SOUTHERN CALIFORNIA EDISON
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ROOT CAUSE EVALUATION
NN 201843216

Steam Generator Tube Wear
San Onofre Nuclear Generating Station, Unit 2

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Disclosure Statement

Consistent with the San Onofre Nuclear Generating Station's corrective action program, this cause evaluation evaluates, through the use of an after-the-fact hindsight-based analysis, conditions adverse to quality and the causes of those conditions. The information identified in this cause evaluation was discovered and analyzed using all information and results available at the time it was written. These results and much of the information considered in this evaluation were not available to the organizations, management, or individual personnel during the time frame in which relevant actions were taken and decisions were made. Consistent with the requirements of 10 C.F.R. Part 50, Appendix B, Section XVI, Edison's cause evaluations have been established as a means to document and "assure that conditions adverse to quality, such as failures, malfunctions, deficiencies, deviations, defective material and equipment, and nonconformances are promptly identified and corrected," and, as necessary, to ensure that actions are taken to prevent recurrence.

This cause evaluation does not attempt to make a determination as to whether any of the actions or decisions taken by management, vendors, internal organizations, or individual personnel at the time of the event were reasonable or prudent based on the information that was known or available at the time they took such actions or made such decisions. Any individual statements or conclusions included in the evaluation as to whether errors may have been made or improvements are warranted are based upon all of the information considered, including information and results learned after-the-fact, evaluated in hindsight after the results of actions or decisions are known, and do not reflect any conclusion or determination as to the prudence or reasonableness of actions or decisions at the time they were made.

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EXECUTIVE SUMMARY

The SONGS Unit 2 Steam Generators (SGs) were replaced during the Cycle 16 refueling outage in the fall of 2009 with new steam generators designed and manufactured by Mitsubishi Heavy Industries, Inc. (MHI) in Japan. Eddy Current Testing (ECT), performed in accordance with the SONGS SG Program and industry standards, was conducted on 100% of the tubes at the completion of the first fuel cycle following replacement.

During the inspections, six tubes with high wear indications (greater than [redacted] percent of the tube wall thickness as defined in the SG Program) were found, four of which, occurred in the vicinity of the retainer bars. Two tubes had excessive wear indications at Anti Vibration Bars (AVBs). There were also minor wear indications at two other locations due to a foreign object. This root cause was initiated for the unexpected wear, not known to exist at other stations, at the retainer bar locations.

Edison obtained the services of industry designers, manufacturers, and consultants to conduct and independently review failure analyses and repair plans pending determination of underlying design and manufacturing issues.

This report includes an assessment of four different wear problems:

- Unexpected wear at the retainer bars (focus of the cause analysis)
- Excessive wear at the AVBs
- Wear due to a foreign object
- Wear on Unit 3 tubes as it relates to Unit 2

MHI is a 10 CFR 50 Appendix B and ASME qualified supplier and as such will be performing an independent root cause analysis. The MHI analysis will address design, organizational, programmatic, and technical aspects that contributed to the observed tube wear.

The purpose of this (Edison) RCE is to determine the Unit 2 tube to retainer bar wear failure mechanism, address the extent of condition in Units 2/3 SGs, and implement corrective actions to prevent the potential for tube to retainer bar wear that can result in a tube leak or tube failure. This RCE also evaluates Edison's oversight of the project focusing on retainer bars. Upon completion of further causal analysis by MHI, Edison will update this RCE to include a discussion of MHI's findings and further analysis of Edison's oversight of MHI's design and manufacturing process.

Mechanistic Root Cause - The retainer bar size was inadequate to prevent the bar from vibrating and contacting the tubes during normal plant operations (inadequate design). The vibration source was turbulent two phase flow (water and steam) across the retainer bars. The retainer bars are relatively longer and smaller in diameter than previous designs by MHI.

The corrective action to prevent a primary to secondary leak is to plug tubes on both sides of the retainer bars (removal from service for heat transfer). A total of 94 tubes have been plugged in each Unit 2 steam generator. This will prevent primary to secondary leak at the retainer bars due to retainer bar vibration. With the tubes plugged, the retainer bars and tubes remain available for their intended function to act as a restraint that limits movement of the AVB assembly within the U-bend region of the tube bundle. In addition to the tube plugging, eight tubes between columns 34 and 56 and six tubes between columns 122 and 144 have been stabilized. This represents stabilized tubes on either side of the retainer bar at each end and at least one point in the middle. This will further limit the ability of retainer bar vibration to cause damage. There were 4 additional tubes that were plugged due to wear at AVB supports. Two were plugged due to exceeding the [redacted] criteria and two were plugged as a preventive measure. The number of plugged tubes due to AVB wear is consistent with first cycle inspections at other plants and as such, will be addressed through the normal SG Program.

It was determined that Edison oversight complied with the Topical Quality Assurance Manual (TQAM). Although the oversight met program requirements, further causal analysis will be performed regarding SCE oversight after the programmatic root and contributing causes are identified in the MHI-specific cause analysis report. Actions will be taken, as appropriate, to further strengthen the oversight program.

SONGS Unit 3 experienced a through wall tube leak on January 31, 2012 after 11 months of full power operation following SG replacement. The ECT results in Unit 3 found free span wear (tube-to-tube) which was the cause of the leak. ECT inspections at the retainer bars in Unit 3 revealed similar wear to Unit 2, but to a lesser extent due to the shorter run time on the Unit 3 SGs compared to Unit 2. RCE 201836127 is being performed to address the causes and corrective actions for the Unit 3 issues.

NOTE: During comment incorporation between CARB approval of this analysis and entry into ActionWay, additional testing was performed on Unit 2 that showed some minor tube-to-tube wear. This wear will be addressed by the Unit 3 RCE.

INTRODUCTION

SONGS Unit 2 is a two loop Combustion Engineering (CE) Pressurized Water Reactor (PWR) which began commercial operation in 1983. The original CE steam generators were replaced in the fall of 2009. The equipment designators for the Unit 2 SGs are S21301ME088 (2E088) and S21301ME089 (2E089)

The Unit 2 first cycle inspection results for the [redacted] tubes revealed a total of six tubes with wear depths greater than [redacted] percent of the tube wall thickness. Four of the affected tubes were located immediately adjacent to retainer bars. There are [redacted] tubes in each steam generator that are immediately adjacent to retainer bars. The retainer bars are part of the free hanging AVB structure that stabilizes the U-bend region of the bundle.

There are a total of 1698 tubes with ECT detectable wear indications at support points in the AVB and TSP locations. Four of these tubes required plugging and stabilizing in 2E088. No additional tubes were plugged in 2E089. The other tube wear indications were determined to be within the SG Program acceptance criteria. Each steam generator has [redacted] tubes which includes an 8 percent ([redacted] tubes) design margin for tube plugging.

A small piece of metallic material (foreign object) was discovered and retrieved from steam generator 2E088 at tube support plate #4. See Attachment 5 for discussion and analysis.

PROBLEM STATEMENT

Governing Requirement or Standard:

SG design drawings show no contact between the retainer bars and SG tubes. Engineering interface minutes indicated a chromium coating was added to the retainer bar to minimize tube/retainer bar wear if contact did occur. The expectation was no detectable wear at the retainer bars.

Deviation or Defect

ECT wear indication in the vicinity of the retainer bars was greater than 35% in four locations. There were three additional locations with wear greater than or equal to 28%.

Consequences of Deviation or Defect

There were no leaks as a result of this defect. The actual consequences include the additional work associated with plugging the four tubes with wear greater than [redacted]% (as required by the SG Program) and loss of the associated heat transfer area. Potential consequences include primary to secondary leakage should a through-wall hole develop.

Interim Actions The interim actions implemented were selected to address the problem, ensure a clear understanding of the extent of condition, and minimize risk during the analysis and corrective active implementation phase of the corrective action program.

SCE obtained the services of industry designers, manufacturers, and consultants to conduct and independently review failure analyses and repair plans pending determination of underlying design and manufacturing issues.

SCE performed 100% tube ECT in accordance with the SG Program and repairs (plugging) on Unit 2. Tubes in the vicinity of the retainer bars were plugged (94 on each SG). Additionally, eight tubes between columns 34 and 56 and six tubes between columns 122 and 144 have been stabilized. SCE conducted Foreign Object Search and Retrieval (FOSAR) and retrieved a loose piece of weld material in Unit 2.

Conduct a primary system change analysis to verify changes in operating parameters will not have an adverse effect on Unit 2 SG operation.

Plug tubes in the vicinity of the retainer bars on Unit 3 in accordance with the SG Program prior to Unit 3 startup.

EXTENT OF CONDITION

SONGS has a total of four SGs (two in each Unit) of the same design from the same manufacturer. The SGs for each unit contain a total of [redacted] tubes. The problem for which extent of condition is being performed is tube to retainer bar wear. Because a comprehensive extent of condition considers all wear mechanisms at all tube locations, all tubes in all SGs were inspected for wear. This represents 100% of the suspect population. Some minor tube wear is expected at typical wear points like AVBs and TSPs, even in the first operational cycle. Wear indications were then evaluated in accordance with the SG Program and EPRI guidelines.

Tube to Retainer Bar Wear:

The retainer bars are internal parts of the steam generators. The retainer bars capture a small group of tubes (Figure 1). The retainer bars also provide support for the AVB assembly during manufacturing and upending during installation. The AVB assembly floats in between the tubes and is held in place by friction. When the tube bundle is rotated during welding of the outer shell and heat treating, the retainer bars ensure the AVB assembly stays in place by acting as a physical stop. However, there is no evidence the retainer bars came in contact with the tubes during these rotations

There are [redacted] total retainer bars of two different diameter sizes in each steam generator. There are two groups of twelve bars. Each group has 6 large and 6 small diameter bars. The different sized bars were needed due to different size tube gaps in different areas. Only tubes adjacent to the smaller bar diameter experienced wear indications. The retainer bars capture two short rows of tubes, which physically stop AVB movement into or out of the bundle. Only those tubes immediately adjacent to both sides of the retainer bars (23 inside and 24 outside) are affected or potentially affected by vibration wear between the retainer bar and tubes. The first captured row is not affected by the retainer bar. (see Figure 1) The extent of tube to retainer bar wear was resolved by plugging and stabilizing tubes in accordance with the SG Program and Condition Monitoring and Operational Assessment (CMOA) report. There was similar wear, although to a lesser degree at the same location in Unit 3.

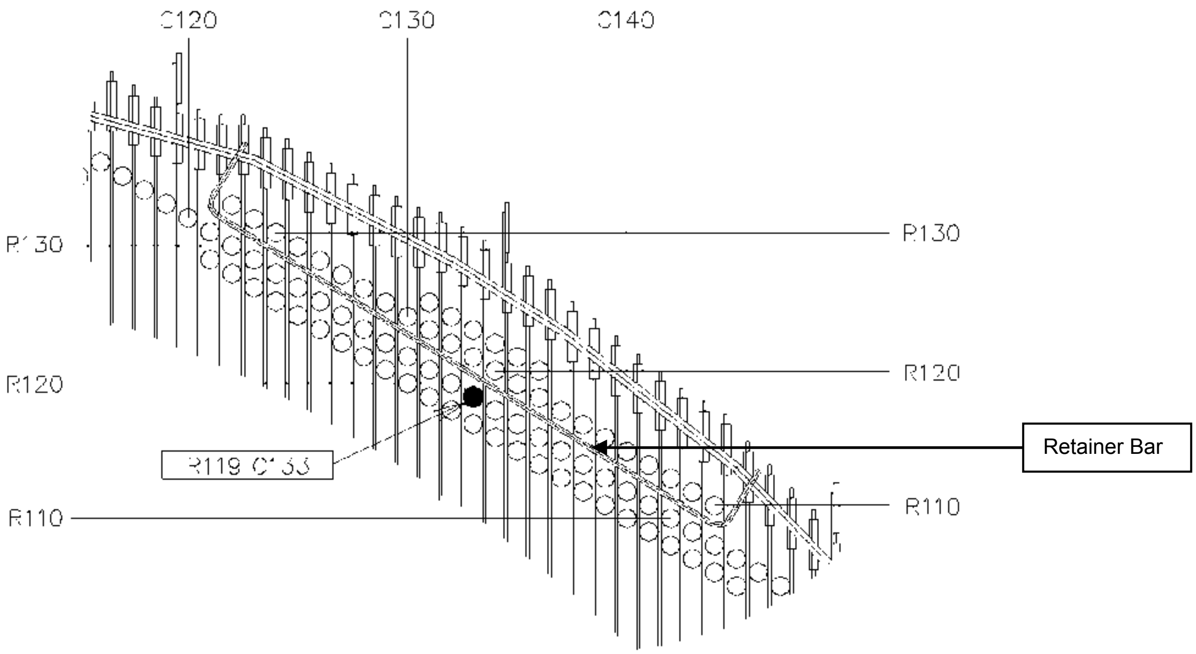

Figure 1 – Retainer Bar

Tube Wear at Other Locations:

The steam generators utilize AVBs to support the tubes in the upper bundle in the out of plane direction and tube support plates to support the tubes in both directions; out of plane and in plane. There are [redacted] tube support plates in each steam generator and up to 12 AVB support points depending on length and diameter of the U-bend for each tube. Wear is only expected at these support points. AVB and Tube Support Plate (TSP) wear was observed in both steam generators. Unit 2 and 3 each had two tubes with wear greater than or equal to [redacted]% (the programmatic limit that requires plugging). Unit 2 had no wear indications greater than [redacted]% at the TSPs while Unit 3 had 230. The extent of tube wear at AVB and TSP locations was resolved by plugging tubes in accordance with the SG Program and CMOA.

Unit 2 and 3 experienced a similar and higher-than-industry-average number of tubes with wear indications at the AVBs and TSPs. The team analyzed data from the next closest plant with a high number of wear indications (St. Lucie – with a higher number of indications) to determine similarities and potential actions. Information from St. Lucie indicates that although the number of indications of tube wear is high, the growth rate has a tendency to drop after the first refueling cycle indicating that although the wear continues, it does so at a lower rate. This will allow tube plugging based on inspections prior to an in-service failure. Unit 3 had a significant portion of deep TSP wear that is attributable to the free span wear mechanism. Because the Unit 2 wear indications are within the SG Program criteria, they do not represent non-conforming conditions or conditions adverse to quality.

There was one occurrence of a foreign object at TSP#4 in 2E088. The foreign object has been retrieved. There were no other foreign objects detected or found in the Unit 2 or 3 steam generators. Tube plugging related to the foreign object was not necessary in accordance with the SG Program

Tube-to-Tube Wear:
Unit 2 completed a full cycle of operation with minor tube-to-tube wear on two tubes in 2E089. This was discovered during comment resolution after CARB approval of this report. It will be addressed in the Unit 3 RCE.This was discovered following CARB approval during comment incorporation, and is being evaluated in connection with the RCE being performed for the causes of the Unit 3 tube leak (RCE 210836127).

EVIDENCE AND FACTS

Steam Generator Summary

Each SG is a U-bend design with [redacted] tubes. There are seven TSPs above the tube sheet with three sets of 2 nested V-shaped AVBs in the U-bend region. The AVBs separate each column of tubes and are welded at the top of the SG to [redacted] retaining bars. There are [redacted] sets of [redacted] retainer bars with [redacted] bridges spanning the retainer bars. The AVBs, retaining bars, retainer bars, and bridges provide the structural support for upper bundle (U-bend region). The upper tube bundle is not attached to the SG shell (free hanging design). See Attachment 4 for the history and system description of the steam generators.

Steam Generator Tubes

- Transfer heat from Primary System (RCS) to Secondary System
- Generate Steam in Secondary to Operate primarily the Main Turbines
- [redacted] U-Tubes per SG
- Inconel 690 Alloy Thermally Treated
- Tube dimensions: outside diameter = 0.75 inch; thickness = 0.043 inch

Steam Generator Tube Support Structures

- [redacted] broached, Tri-foil, flat land Tube Support Plates
- [redacted] stainless steel
- Designed to prevent denting caused by corrosion products
- Support Plate contact geometry provides additional margin for impurities concentration

Steam Generator U-bend Supports

- There are up to 6 V-shaped AVBs between adjacent tube columns.

- Provides up to 12 support points per tube in the U-bend region.
- AVBs are nearly perpendicular to tube centerline to provide out of plane support and minimize wear contact.

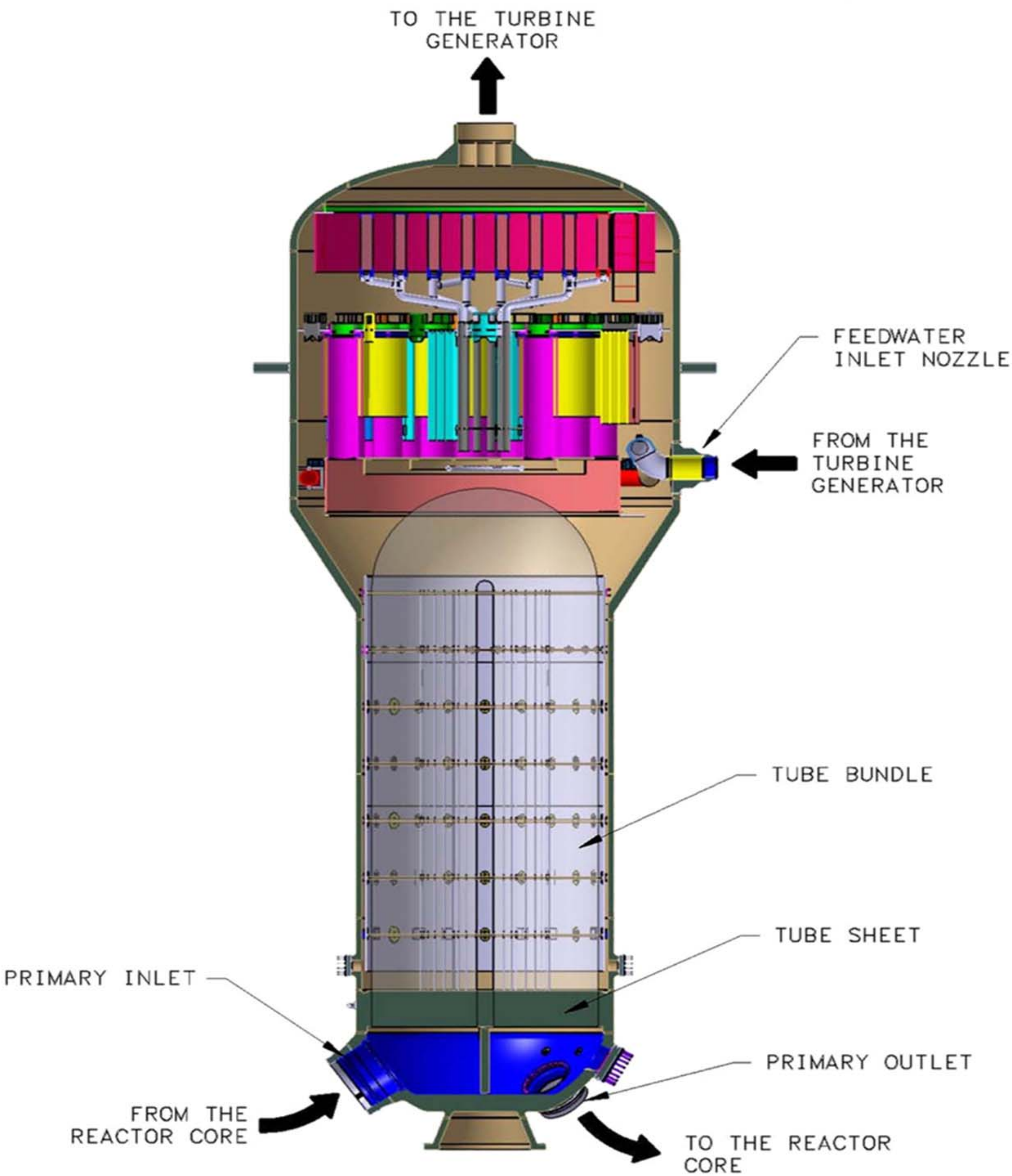

Figure 2 - SONGS Steam Generator

US Industry Information

46 Units in US with 690Thermally Treated tubing:*

- 44 of 46 units completed first In Service Inspections (SONGS 3 and Crystal River remaining).
- A total of 460 tubes plugged for wear in the first cycle inspections for all 44 units.
- Based on industry average, SONGS Unit 2 is comparable in plugged tubes for AVB and TSP wear. (SONGS Unit 2: 4 tubes - AVB wear; 0 tubes - TSP wear).
- There were no known indications outside SONGS of retainer bar wear.

*Note: Actual number of steam generators per operational unit, varies between 2 and 4. The majority of these plants have much smaller steam generators. Only steam generators for the Palo Verde Nuclear Generating Station units are larger than those for SONGS.

Initial Refueling Cycle Inspection Plan (U2)

- In service time – 627 days
- 100% Bobbin Eddy Current Testing (ECT)
- Sludge Lance
- Foreign Object Search and Retrieval (FOSAR)
- ECT and FOSAR required by Technical Specifications referring to EPRI guidance
- Sludge lance per industry practice

MHI SG Supply Experience

- US: 6 SGs (SONGS, Ft. Calhoun)
- Belgium: 10 SGs
- Japan: 92SGs
- France 6 SGs
- Total Number of SGs supplied: 114
- The SONGS SG are the largest designed and built by MHI.

ANALYSIS AND CAUSES

The analysis was performed using: Event and Casual Factor (E&CF) Charting, Barrier analysis, ECT results analysis, and comparison of Unit 2 to Unit 3 wear location and extent. The ECT results were used as input to the E&CF charting and barrier analysis. The results of the barrier analysis support the E&CF chart conclusions.

Evaluation of Data

Retainer Bar Length

The AVB assembly was initially identified by SCE as a critical component for the design review phase. The retainer bar is a subcomponent of the AVB. When the retainer bar design was questioned by SCE, MHI informed SCE personnel that the retainer bars were not a critical component because of its function (during fabrication and steam line breaks), location (not in contact with the tubes) and due to significant previous MHI experience (no indications of tube wear at the retainer bars). As described in the MHI evaluation, Retainer Bar Tube Wear Report, the retainer bar length is almost twice the length of the next longest retainer bar in any previously-manufactured MHI steam generator ([redacted] for Edison contrasted with [redacted]). In addition, the retainer bar also has a smaller diameter than the next smallest diameter retainer bar ([redacted] for Edison compared with [redacted]). The greater length and smaller diameter result in a lower natural frequency of the bar (see Table 1).

MHI Evaluation of the Problem

An evaluation by MHI of the retainer bar to tube wear was conducted at the request of Southern California Edison after the wear indications were found. The eddy current inspection data indicates material loss on the tubes at a location that coincides with the position of the lower retainer bars at AVBs 02 and 03 on the hot leg side of the U-bend and at AVBs 10 and 11 on the cold side (see Table 2). Wear is the result of movement of the retainer bar. Up until this event, there has been no report of tube wear at a retainer bar in any MHI steam generator. The SONGS retainer bars are longer and smaller in diameter than those in other steam generator designs.

Table 1 - Retainer Bar Design Comparison (MHI ¾" tube Units)

Plant	**Number**	**Diameter** (in.)	**Length** (in.)	**Height** (in.)	**Tubes Inside/ Outside**	**Frequency** (Hz)
SONGS 2/3	[redacted]					
European Plant B						

	[redacted]
USA Plant D	[redacted]
European Plant A	[redacted]
European Plant C	[redacted]

(Note: natural frequencies of retainer bars were previously calculated by MHI but not provided to SCE)

The equation used to calculate the natural frequency is:

$$f_n = \frac{1}{2\pi}\left(\frac{\lambda_K}{L}\right)^2 \sqrt{\frac{EI}{\rho A}}$$

λ_K : Coefficient based on the vibration mode
L: Length of the structure
E: Modulus of elasticity
I: Moment of inertia
ρ: Density
A: Sectional area

For SONGS, as shown on the next page, the thinner bar design (bar length and diameter or [redacted] frequency) lies in the critical velocity cross flow range, i.e., results in large vibration amplitude of the bar that can wear of the adjacent tubes as observed in Unit 2 Steam generators

[redacted]

As shown on the above graph, the large retainer bar is not susceptible to flow induced vibration due to the limited velocity range experienced during normal operation. Additionally, even if excited at the natural frequency, the thickness of the bar would limit the amplitude of the vibration to approximately one tenth that of the smaller bar resulting in minimal wear on the tubes.

As can be seen in Table-1, the natural frequency of the smaller diameter retainer bars for SONGS is significantly lower than the natural frequency of the retainer bars in the other SGs. This lower natural frequency makes the retainer bar more susceptible to high displacement vibration, the type that would allow the retainer bar move enough to contact the tubes. The evaluation concluded that the vibration source is turbulent two phase flow (water and steam) across the retainer bars combined with the relatively lower natural frequency of the retainer bar. It was concluded the retainer bar vibration was the primary contributor instead of tube vibration since there was minimal to no wear at the TSPs and AVBs for these tubes. Although chromium plating was applied to the retainer bar to minimize tube wear should contact between a bar and tube occur, it was done without consideration of excessive vibration of the retainer bar.

The following was extracted directly from the MHI Retainer Bar Tube Wear Report Revision 1.

Turbulence-Induced Vibration (Random Vibration) - “This mechanism was not considered in the design phase, because generally the fluid force of this mechanism is small enough in the normal two-phase flow in the SG secondary side, and the natural frequency of the structure is high enough that structures are not expected to vibrate excessively.”

Table 2 – Retainer Bar Tube Wear

SG	Row	Col	Location	Side	Depth %TWD
2E088	124	48	B03	In	47%
2E088	125	49	B03	In	54%
2E089	118	44	B11	Out	30%
2E089	119	133	B02	Out	90%
2E089	120	132	B10	Out	28%
2E089	120	132	B11	Out	29%
2E089	127	127	B03	In	38%

"However a re-evaluation of this mechanism found that this is considered to be a possible cause of the retainer bar vibration, based on the peculiar flow around the retainer bar, combined with the rather low natural frequency of the retainer bar…"

"Since none of the tubes that are identified for plugging show any indication of AVB wear or TSP wear, it is concluded that they are fully supported and stable and that the retainer bar is the sole cause of the wear."

"However, the retainer bar vibration amplitude, in the unrestrained condition is shown to be less than 0.08" so the maximum tube wear depth is limited to less than 10% of the tube diameter."

"…that these tubes can conservatively sustain the maximum retainer bar displacement without severing." (intended to show that the tubes that contact the retainer bar will not sever)

"...analysis confirms the structural integrity of the weld for this condition." (intended to show that the retainer bar to retaining bar weld will not fail)

Evaluation Summary

The tube wear at the retainer bars is a result of retainer bars making contact with adjacent tubes. MHI concluded that wear was primarily due to retainer bar vibrations based on the absence of tube wear at the corresponding AVB and TSP supports. This indicates that the tube vibration is minimal and that the contact source is from the retainer bar.

The wear was isolated to the smaller [redacted] inch diameter bars at AVB 02 and AVB 03 on the hot leg and AVB 10 and AVB 11 on the cold leg side. There was no wear on the smaller diameter bars at locations AVB 01 and AVB 12. The flow velocity at these locations is lower than the other locations. The velocity at AVB 01 is estimated to be [redacted] ft/s, which is lower than [redacted] ft/s at AVB 02 location. There was no wear at the larger [redacted] inch diameter retainer bars.

The retainer bars have a lower natural frequency based on length and diameter compared to previous MHI designs. The low frequency coupled with two phase flow across the bar is sufficient to excite the bar to a vibrating state. The following is an evaluation of the potential weld failure due to fatigue stress:

1. Per ASME Section III, Division 1 Design Fatigue Curves for Austenitic Steels, Nickel-Chromium-Iron Alloy, Nickel-Iron-Chromium Alloy and Nickel-Copper Alloy for Temperatures not Exceeding 800°F, SCE agrees the fatigue limit of the weld is 13.6 ksi
2. SCE accepts MHIs calculation that the stress at the weld equals 1 ksi is accurate
3. Per ASME Code, "Evaluation for cyclic loading shall be made in accordance with Appendix XIV using a fatigue strength reduction factor of four…" Therefore, an FSRF of 5 is sufficient. SO23-617-1-M1562 Rev 2 uses an FSRF of 7; this value is also acceptable.

Weld Peak Stress = WPS = (FSRF) x (Stress at Weld)

Fatigue limit = [redacted] ksi
Stress at weld = [redacted] ksi
WPS for Rev 1 = [redacted]
WPS for Rev 2 = [redacted]
Fatigue limit > WPS for Rev 1
Fatigue limit > WPS for Rev 2

Even with an FSRF of 7, there is enough margin to conclude that the peak stress at the weld will not reach the fatigue limit.

Plugging of tubes at both sides of the retainer bar ([redacted] total) will prevent future leaks from retainer bar vibration. This removes the tubes from service for heat transfer such that primary fluid flow through the tubes no longer occurs. The tubes still provide physical restraint capability for the retainer bars. The retainer bar function remains fully capable with the tubes plugged. Plugging of the tubes for the smaller retainer bars also addresses possible vibration related wear of the larger retainer bars (a concern because they also have a relatively low natural frequency). Because there has been no wear detected at the larger retainer bars, and the tubes will be plugged, no additional analysis of the low natural frequency of the large retainer bars is necessary. SCE has evaluated the potential for retainer bar failure and, based on the chromium coating being harder than the alloy 690, the retainer bar thickness being approximately four times that of the tube thickness, tube not being worn all the way through, and future monitoring of retainer bar integrity, there is adequate control of the retainer bar. In addition to the [redacted] tubes plugged for the retainer bar issue, four tubes were plugged to address AVB wear. Two were plugged for exceeding the 35% criteria and two were plugged as a preventive measure.

Eddy Current Testing Results

Eddy-current testing was performed to identify the scope of the condition elsewhere, and actions to resolve the wear indications initially identified. The table below shows the results of the testing and compares Unit 2 to Unit 3. The numbers of significance are bolded for ease of identification.

Table 3 – ECT Summary

Degradation Type	**Unit 2**			**Unit 3**		
	Number of Tubes	Total Indications	**Tubes with Deep Wear (≥35% TWD)**	Number of Tubes	Total Indications	**Tubes with Deep Wear (≥35% TWD)**
AVB Wear	1,399	4,348	2	1,767	6,507	2
TSP Wear	299	364	**0**	463	2,950	**230**
Retainer Bar Wear	**6**	7	**4**	**4**	4	**3**
Foreign Object	2	2	0	0	0	0
Tube-to-Tube Wear	0	0	**0**	326	829	**202**

Note: Table provides total tubes with wear type. A single tube may have AVB, TSP and Tube-to-Tube wear simultaneously. Total indications are tabulated by type of wear and may occur at several locations within the same tube. Wear other than retainer bar related is being addressed in accordance with the SG Program.

ECT data did not show contact between the retainer bar and tubes when the ECT was performed. Although not conclusive for normal operating conditions, it shows that the AVB assembly did not move sufficiently to cause the retainer bar to come in contact with the tubes such that any movement (bar or tube) would cause rubbing wear.

Anti-Vibration Bar Wear

Unit 2 experienced a higher-than-industry-average number of tubes with wear indications at the AVBs. The team analyzed data from the next closest plant with a high number of wear indications. St. Lucie has a different design and a higher number of indications. Although a different SG design, the AVBs serve the same design function so St. Lucie was used to determine similarities and potential actions. Information from St. Lucie shows that even though the number of tube wear indications is high, the growth rate has a tendency to drop after the first refueling cycle. This indicates that as the wear continues, it does so at a lower rate. The lower initial value in conjunction with the decreased wear rate after the first cycle provides confidence that the SG Program will allow tube plugging based on inspections prior to an in-service failure. Unit 3 had a similar number of tubes affected although a significant portion of the AVB wear is attributable to the free span wear mechanism.

Similarity between Units 2 and 3 is to be expected based on design, operating conditions, and manufacturing techniques with some exceptions not related to retainer bar wear. Where there is an additional difference between Units 2 and 3, it is with the type of wear at the AVB. Unit 2 shows only typical contact wear. Unit 3 shows typical contact wear in some locations and in-plane wear at other locations indicating a different wear mechanism. Unit 3 in-plane wear is being addressed by RCE-201836127.

Tube Support Plate Wear

Unit 2 experienced a higher-than-industry-average number of tubes with wear indications at the TSPs. The team analyzed data from the next closest plant with a high number of wear indications (St. Lucie – with a lower number of indications) to determine similarities and potential actions. For Unit 2 there were no deep-wear indications. So, although the number is high, the degree of wear depth does not pose an immediate risk and can be managed within the SG Program.

Transportation and Installation

A review of the transportation and installation activities did not result in identification of any issues that likely would have caused the retainer bar wear in Unit 2. The accelerometer data from the Unit 2 steam generator shipping skids was evaluated by MHI and did not reveal any large events during shipping that required further evaluation.

Installation was performed by Bechtel Power Corp. with Rigging International, Inc. as the heavy equipment subcontractor. A search was performed in SAP for Notifications pertaining to steam generator rigging. There were no rigging events identified which resulted in an impact load on any steam generator.

Transportation and installation are not likely contributors.

Fabrication Non-Conformances

A review was performed of Non-Conformance Reports (NCRs) and Supplier Disposition Requests (SDRs). An SDR is required for all supplier issued NCRs which are dispositioned by the supplier as “Use-As-Is”. For the steam generator replacement project, 225 total NCRs (145 in Unit 2 and 80 in Unit 3) were written by MHI. 104 total SDRs were written. Of this total SDR/NCR population, 19 SDR/NCRs potentially related to fabrication in the area of the AVB assembly were selected for more detailed review based on the NCR/SDR title. Of the 19 SDR/NCRs reviewed in detail, only the following four SDR/NCRs were specifically related to fabrication in the area of the retainer bars:

SDR-051 43366-07051 / UGNR-SON2-RSG-067

SDR-053 43366-07053 / UGNR-SON2-RSG-075
SDR-059 43366-08059 / UGNR-SON3-RSG-030
SDR-063 43366-08063 / UGNR-SON3-RSG-024

These four SDR/NCRs were related to gaps between tubes and AVBs. The design of the AVBs is to prevent out-of-plane motion. As such a verification of gap size between the tube and the AVB on each side using a feeler gauge was performed during fabrication. These SDR/NCRs were created to document gaps greater than acceptance criteria. These SDR/NCRs were dispositioned as use-as-is by MHI and accepted by SCE based on analysis that the increased gap would not impact the design function of the AVBs (to prevent out-of-plane motion).

All four steam generators had similar tube to AVB gap spacing issues and did not have any gap spacing issues clustered in one specific location in the tube-bundle. Since the issues were similar in nature, distributed throughout the tube bundle, and resolved using the same process, these non-conformances are not likely a source of the problems with the retainer bars. And, since there were no other SDR/NCRs related to fabrication in the area of the retainer bars, fabrication non-conformances in general are not likely a source of the retainer bar problems.

Vibration and Loose Parts Monitor System
The vibration and loose parts monitor system (VLPMS) data was reviewed. Unit 2 did not experience alarms. The VLPMS data was sent to Westinghouse for analysis in December 2011 with no confirmable results of a loose part.

The VLPMS sensors are located on the support skirt at the bottom of the steam generators. As the sensors are mounted on the support skirt, the system primarily detects loose parts in the channel head on the cold or hot leg in the Reactor Coolant System. It would be difficult to detect most noise issues on the secondary side. It would likely detect loose material on the tube sheet, and not at the tube support plates, tube-to-tube, or tube-to retainer. NECP 800457837 will relocate the sensors in Unit 2 with one sensor to be located at the tube sheet. This should improve loose parts detection on the secondary side and may provide indication of other abnormalities

Design and Fabrication Oversight of the Retainer Bars

The original steam generators at SONGS Units 2 & 3 were manufactured by Combustion Engineering in the 1970s. After SONGS Units 2 & 3 were placed in service, Industry experience determined that the steam generators were susceptible to degradation mechanisms including stress corrosion cracking and tube wear. SONGS decided to replace the steam generators in 2001. An organization was created to procure and install the Replacement Steam Generators (RSG). The RSG team developed an equipment specification based upon extensive industry operating experience, incorporating requirements that reflected industry best practices and technological advances. It should be noted that a review of OE did not find wear in tubes at retainer bars for replacement steam generators.

The specification was released for bid in December of 2003. There were no domestic suppliers of steam generators at that time. There were six foreign firms capable of fabricating steam generators for the US nuclear industry:

- Doosan Heavy Industries & Construction (South Korea)
- Mitsubishi Heavy Industries (MHI) (Japan)
- Babcock & Wilcox (B&W) (Canada)
- Framatome ANP (France)
- Equipos Nucleares, S.A. (ENSA) (Spain)
- Ansaldo-Camozzi Energy Special Component, S.p.A. (Italy)

The RSG design and fabrication contract was awarded to MHI in September 2004. At the time of the bid, none of the potential RSG suppliers had designed, fabricated, and delivered replacement steam generators of the size required for SONGS. A close exception was Ansaldo, which had fabricated, but not designed, the first set of Palo Verde replacement steam generators. The Palo Verde SGs are slightly larger than SONGS. Westinghouse, which had purchased Combustion Engineering, performed the design of the Palo Verde SGs.

The SONGS replacement steam generators were larger in size for MHI from its Westinghouse licensed standard design. Edison Project Management determined that the normal design and fabrication oversight process be proactively augmented. To accomplish this, Edison added special program elements to provide additional oversight and control for the RSG design and fabrication process. One of the additional elements attempted was the use of third party review. The typical third party review was not performed on this project for two primary reasons 1) the number of personnel with SG design experience is very limited and typically associated with SG design/manufacturing companies and 2) the companies with these personnel are in competition with each other and not willing to share proprietary design information. Since SCE was not in a position to make the third party review happen, they recommended and MHI complied with bringing in outside SG design expertise. This consisted of two retired SG design engineers.

Potential wear in the tube bundle was discussed from the start of the design. As a result of those discussions, a special team of independent industry experts was assembled to participate in the design process for the RSGs and the upper bundle in particular. At first, there did not appear to be a focus on possible wear from the retainer bars (previous discussions were based on AVB assembly and potential damage). MHI does not typically perform an analysis of the retainer bar that addresses flow induced vibration. As seen in Table 1 (pg. 13), previous retainer bar designs have higher natural frequencies that reduce the potential for flow induced vibration.

Conversely, when the question of potential retainer bar wear of the tubing was asked of MHI by Edison in 2006, MHI indicated that the tubing and retainer bars do not interact (the design calls for a reference clearance of at least [redacted] mils). Operational experience shows that there is no tube wear issue from retainer bars in previous steam generators. However, as a conservative measure in the design (in case the retainer bars and tubes actually contacted each other) MHI provided additional chromium plating of the retainer bar to reduce the wear coefficient and minimize any potential tube wear. Additionally, as a result of an Edison question regarding retainer bar size as shown on a drawing with a different size used in a stress calculation, retainer bar thickness was corrected from [redacted] inch to [redacted] inch.

It should be noted that the Edison comments were based on the fact that tubes vibrate and thus have movement. Edison did not ask about the possibility of vibration in the retainer bar since MHI had stated that the retainer bars would not contact the tubes. As such, the additional chromium plating was accepted as a reasonable response based on the pre-defined spacing gap and the fact that the tubes themselves do not significantly move. Edison did not recognize the potential for retainer bar vibration based upon MHI's statements regarding lack of contact with retainer bars.

The standard or basic Edison supplier oversight process for Safety Related equipment has two components. The first component is associated with Quality Assurance - audits of a supplier and receipt inspection by Edison Nuclear Oversight Division (NOD). The second revolves around the review and approval of supplier design documentation by Edison engineering.

SCE initially utilized a third-party 10 CFR 50 Appendix B audit of MHI (conducted by Dominion in 2002), which is an industry accepted practice, to place MHI on the SONGS approved supplier list. The SONGS review of the Dominion audit was conducted in September 2004 and resulted in Conditionally Qualifying MHI with the following condition "MHI is conditionally qualified for the fabrication and design of Steam Generators as delineated in the SCE Steam Generator Replacement Specification. An audit will be performed when sufficient quality work has been performed to demonstrate implementation of the functions defined in the QA program." An SCE limited scope audit was performed in November 2004. The scope included Order Entry, Design, Procurement, Corrective Actions, Control of Nonconformances, and Internal/External Audits. Joint Utility audits led by SONGS utilizing the NUPIC Checklist were completed in 2006 and again in 2009.

San Onofre's Topical Quality Assurance Manual and procedures require that for a Level II procurement (i.e., supplier performs work under its QA Program and equipment is accepted from supplier based on a Certificate of Compliance/Conformance and receiving inspection) suppliers be audited from a performance based approach to assess their capability to meet industry nuclear standards. Once successfully audited, the supplier must be re-audited every three years unless a significant change in the QA Program or performance warrants an audit sooner.

A total of three audits were performed on MHI's design and fabrication programs over the course of the project. These audits uncovered deficiencies in MHI's programs that were subsequently corrected by the supplier:

- Incorrect or insufficient technical information in RSG design documents
- Procedural non-compliance with design verification and unapproved software
- Deficiencies in corrective action/NCRs, 10CFR21, and internal/external audits
- Deficiencies in audit report issuance and corrective action timeliness

For the deficiencies identified during the audits, SCE Corrective Action Requests (CAR) were issued to MHI. Vendor Oversight evaluated the responses to the CARs and verified the implementation of the corrective actions by MHI prior to closing the CARs.

The engineering review and approval process of supplier equipment design is controlled by Edison procedure SO123-XXIV-37.8.26, Processing of Supplier Documents and SO123-XXIV-1.1, Document Review and Approval Control. Supplier documents are submitted to Edison in accordance with the specification and contractual requirements. Normally, the scope of review is for arrangement and conformance to the specification only. Edison approval does not relieve the supplier from the responsibility for adequacy and suitability of design, materials, and/or equipment represented. To augment the normal oversight process, special program elements were added:

1. NOD conducted additional quality verification audits of critical manufacturing processes.
2. NOD had an on-site full time assessor.
3. Edison Engineering increased the level of document reviews to challenge basis for assumptions and methodologies in the design and their results.
4. Edison held periodic design review meetings with MHI.
5. Edison utilized industry consultants for review of critical design aspects (although not done for the AVB assembly).

Edison design engineers are competent in engineering fundamentals and in the design bases of plant structures, systems and components at SONGS. As such, the review of supplier documents is focused on critical design requirements, industry operating experience, and maximizing margins for a design. Edison does not design and fabricate large equipment such as steam generators and does not maintain the in-house expertise, analytical tools, models, and basic research/empirical data to do so. Consultants with specialized skills (e.g. weld repair, structural experts) were utilized to augment Edison's internal resources. Consequently, the project philosophy developed for oversight of MHI was to implement the normal process with augmented reviews and audits that selectively challenged MHI assumptions, methodologies, techniques, processes, and tools to verify a prudent approach to the design and fabrication of the replacement steam generators.

Edison decided that it would ensure it had an enhanced oversight effort in areas that were determined to represent current performance issues in the industry (e.g., tube wear) and areas that due to the size increase might result in performance deficiencies if incorrectly executed. Consistent with Edison's QA Program, all areas would undergo, as a minimum, the normal review process but these areas of focus would receive this augmented level of attention.

The AVB structure (which includes the retainer bars) was prioritized for an augmented level of attention, specifically the potential for tubing wear from the interaction with the AVBs. The retainer bar is a small element of the AVB structure which does not normally interact with the tubing during operation. The primary purpose of the retaining bar is to prevent the AVB assembly from displacement during a main steam line break event. As such the design of the retainer bar itself was not identified for this augmented level of attention. In addition, the retainer bar is part of the proprietary standard design originally developed by Westinghouse and adapted by MHI, to which Edison did not have access. Edison was not aware that the MHI selected size and length represented a departure or change from the standard design. The reviews by Edison were focused on reducing tube wear that might have been caused by tube movement and retainer bar contact. This led to the diameter increase of the selected retainer bars and additional chromium plating thickness. MHI also added a stress analysis for the retainer bars to the AVB calculation as requested by Edison. However, MHI did not include the retainer bars in the flow induced vibration analysis.

<u>Timeline for Edison RSG Retainer Bar Oversight</u> (Summarized)

- March 17 & 18, 2005: MHI & Edison personnel discuss initial design and design criteria for the Anti-Vibration Bars (AVBs). Assembly sequence for the retainer bars is discussed.
- May 20, 2005: At the Executive Meeting in Kobe Japan, Edison "expressed concern about the wear of the AVB...." Edison "requested a systematic gathering of information in order to address industry problems and optimize the AVB design ..." A special team was to be constituted to respond to the request. Edison pressed for inclusion of specific expertise in the area of concern. MHI brought in a third party to participate in the review of design development but no special team was formed (*SCE attempted to establish a third party review but due to the limited number of industry experts outside of major companies and the proprietary nature of the information on design, no third party review could be established*)
- June 15, 2005 to October 18, 2005: Numerous video conferences, Technical Meetings, and a Design Review Meeting are held by the Special AVB Team. Design details of the AVB System are discussed, analysis reviewed, benchmarking results covered, wear results reviewed, and decisions made on key design features. Discussions were primarily focused on the retainer bars related to assembly issues or concerns
- December 5, 2005: Comments are returned on Drawing L5-04FU117 design drawing AVB Assembly Sheet 7/9, which shows the retainer bar design. One

comment requested that MHI "demonstrate that no denting will occur at the contact points between Tubing and Retainer Bars due to design loads." Resolution was to defer this comment to Calculation L5-04GA419.

- June 12, 2006: Drawing L5-04FU117 design drawing AVB Assembly Sheet 7/9 Revision 2 (which shows the retainer bar design) is issued. This change increases the size of the smaller diameter retainer bar from [redacted] This change initiated from Edison comment regarding inconsistent size between a retainer bar weld calculation and drawing.
- September 13, 2006: Technical Meeting on AVB fabrication. During the meeting, the retainer bar was discussed. Edison "asked about potential contact between the tubes and the retainer bar and asked if there was any special wear potential at these sites." Meeting minutes indicate that "The retainer bar material is chromium plated Alloy 690. The chromium layer is present to minimize tube wear." Discussions were held on retainer bar to tube clearance with MHI indicating a target clearance of [redacted] mils at assembly.
- September 14, 2006: Core Team Meeting on AVB Installation Risk Analysis. During the meeting, Edison and MHI discussed tube to retainer bar contact during fabrication for horizontal tube sag.
- September 15, 2006: During a discussion of AVB Open Items, Edison expresses a concern over "wear between the retainer bar and the tube." The documented resolution to the concern is to ensure a chromium thickness on the retainer bar, [redacted] to minimize wear and not expose retainer bar base metal, Alloy 690)

This demonstrates there was active engineering involvement in AVB design from the beginning, the involvement was intrusive for areas of known problems and resolution was obtained. Even though there was active oversight, and the function and potential impact of the retainer bars was questioned, SCE was not aware there could be a vibration related issue for which a retainer-bar-specific vibration analysis was required. There was no MHI document produced associated with retainer bar vibration that could have been reviewed and questioned by SCE personnel. It was determined that Edison oversight complied with the Topical Quality Assurance Manual (TQAM). Although the oversight met program requirements, further causal analysis will be performed regarding SCE oversight after the programmatic root and contributing causes are identified in the MHI-specific cause analysis report. Actions will be taken, as appropriate, to further strengthen the oversight program.

CAUSES AND CORRECTIVE ACTIONS

MECHANISTIC ROOT CAUSE:

Inadequate Design: The retainer bar size was insufficient to prevent excessive flow induced vibration of the bar. Tube wear occurred from vibrational contact between the retainer bars and tubes inside the SGs.

CORRECTIVE ACTIONS

Cause Evaluation Element	**Description**	**Assignment Number & Type/Assignee/Due Date/Signature:**
Problem: *On February 5, 2012, wear indications greater than 35 percent were detected in two locations in Unit 2 steam generator adjacent to retainer bars during the Unit 2 Cycle 17 refueling outage current examinations.*	CAPR1: Removed the 94 steam generator tubes from service at the retainer bar locations in 2E088 and 2E089 in accordance with SO23-SG-1 Steam Generator Program requirements and the Condition Monitoring and Operational Assessment Report (CMOA). *This will prevent vibration between the retainer bar and tubes from creating a leak. This CAPR will be captured programmatically by adding a note to the SG tube map indicating which tubes were plugged as a CAPR from this report.*	Assignee: A. Matheny Due Date: **Complete** *(This action is complete. This action is being entered into ActionWay to ensure adequate documentation (objective evidence) of performance is provided. The due date is for documentation entry only. Due 5/15/12)*
Interim Actions:	CA1: Obtain the services of industry designers, manufacturers, and consultants to conduct and independently review failure analyses and repair plans pending determination of underlying design and manufacturing issues.	Assignee: B. Sarno Due Date: **Complete** *(This action is complete. This action is being entered into ActionWay to ensure adequate documentation (objective evidence) of performance is provided. The due date is for documentation entry only. Due 5/15/12)*

	CA2: SCE performed 100% tube ECT in accordance with the SG Program and repairs (plugging) on Unit 2. Tubes in the vicinity of the retainer bars were plugged (94 on each SG).	Assignee: A. Matheny Due Date: **Complete** *(This action is complete. This action is being entered into AcctionWay to ensure adequate documentation (objective evidence) of performance is provided. The due date is for documentation entry only. Due 5/15/12)*
	CA3: Conduct Foreign Object Search and Retrieval (FOSAR) and retrieve any loose parts in Unit 2.	Assignee: A. Matheny Due Date: **Complete** *(This action is complete. This action is being entered into AcctionWay to ensure adequate documentation (objective evidence) of performance is provided. The due date is for documentation entry only. Due 5/15/12)*
	CA4: MHI to perform vibration analysis on retainer bar and submit to Edison for approval.	Assignee: B. Olech Due Date: 6/15/12
	CA5: Conduct a primary system change analysis including the planned T_{Cold} change to verify changes in operating parameters will not have an adverse effect on Unit 2 SG operation.	Assignee: F. Simma Due Date: **Complete** *(This action is complete. This action is being entered into AcctionWay to ensure adequate documentation (objective evidence) of performance is provided. The due date is for documentation entry only. Due 5/15/12)*
	CA6: Establish operational limits that will allow operation between start-up and initial mid-cycle inspection.	Assignee: D. Yarbrough Due Date: 6/01/2012
	CA7: Increase the tube inspection scope and frequency in accordance with the SG Program and CMOA.	Assignee: A. Matheny Due Date: 6/01/2012
	CA8; Monitor the Unit 3 tube-to-tube wear cause analysis. If it impacts Unit 2 operational limits and mid-cycle inspection dates, generate a notification to track analysis and resolution.	Assignee: A. Matheny Due Date: 6/30/2012

Extent of Condition: This evaluation determines the cause of wear at the retainer bars and other wear locations.	CA9: Remove the [redacted] steam generator tubes from service at the retainer bar locations in 3E088 and 3E089 in accordance with SO23-SG-1 Steam Generator Program requirements and the Condition Monitoring and Operational Assessment Report.	*The action as written here is intended to address extent of condition. It is the same action as CAPR2 which addresses the mechanistic root cause. See closure documentation for CAPR2.*
	CA10: Perform secondary side visual inspections of both Unit 2 steam generators.	Assignee: A. Matheny Due Date: **Complete** *(This action is complete. This action is being entered into ActionWay to ensure adequate documentation (objective evidence) of performance is provided. The due date is for documentation entry only. Due 5/15/12)*
	CA11 Plug four additional tubes with wear at AVB locations (two because the [redacted] criteria was exceeded and two as a preventive measure).	Assignee: A. Matheny Due Date: **Complete** *(This action is complete. This action is being entered into ActionWay to ensure adequate documentation (objective evidence) of performance is provided. The due date is for documentation entry only. Due 5/15/12)*
Mechanistic Root Cause: The retainer bar size was insufficient to prevent excessive flow induced vibration of the bar. Tube wear occurred from vibrational contact between the retainer bars and tubes inside the SGs.	CAPR1: Removed the 94 Unit 2 steam generator tubes from service at the retainer bar locations in 2E088 and 2E089 in accordance with SO23-SG-1 Steam Generator Program requirements and the Condition Monitoring and Operational Assessment Report (CMOA). *This will prevent vibration between the retainer bar and tubes from creating a leak.*	Assignee: Al Matheny Due Date: **Complete**
	CA12: Determine additional preventive actions based on findings from Unit 3 cause analysis.	Assignee: Al Matheny Due Date: 6/1/2012

	CA13: Review St. Lucie Unit 2 SG Inspection Results for Third Cycle following replacement for continued applicability of AVB wear rates at SONGS.	Assignee: Al Matheny Due Date: 10/1/2012
	CA14 Review MHI cause analysis report and revise this report based on MHI causes and conclusions. Present both reports to CARB.	Assignee: J. Osborne Due Date: 6/30/2012

Causes: Extent of Cause	CAPR2: Remove the 94 Unit 3 steam generator tubes from service at the retainer bar locations in 3E088 and 3E089 in accordance with SO23-SG-1 Steam Generator Program requirements and the Condition Monitoring and Operational Assessment Report. *This will prevent vibration between the retainer bar and tubes from creating a leak. This CAPR will be captured programmatically by adding a note to the SG tube map indicating which tubes were plugged as a CAPR from this report.*	Assignee: Al Matheny Due Date: 6/30/12
	OA1: Conduct a design change review between a proven similar MHI replacement reactor vessel head and the SONGS replacement reactor vessel head to identify design changes and verify those changes received the appropriate level of analysis. Add a note to the action that the due date was set by CARB and cannot be changed without CARB approval.	Assignee: B. Patel Due Date: 5/30/12

Other Actions:	OA2: Chemistry Effluent Engineering perform an evaluation of the Primary to Secondary Leak (PSL) program controls to determine if detection limits can be lowered and if administrative actions can be added to detect low level trends of PSL. Consider the addition of new/improvements to rad-monitoring and changes to plant operations during the event.	Assignee: J. Demlow Due Date: April 30, 2012
	OA3: Management sponsor for RCE to submit to CARB an approved Change Management Plan in accordance with SO123-XV-50.7 within 15 calendar days after CARB approval of the RCE.	Assignee: Gary Kline Due Date: 4/17/12.
	OA4: Approve the Condition Monitoring & Operational Assessment Report by AREVA to determine the cycle length for next inspection for operation.	Assignee: Al Matheny Due Date: 6/15/2012
	A FIV analysis was not performed for the small retainer bars. The purpose of this action is to ensure that changes made to a SONGS system that involve components in the flow stream receive some level of vibration analysis. OA6 revise SO123-XXIV-1.1 to require check of vibration analysis for changes to systems involving the flow aspect of the system. (see OE section on previous SONGS events to understand concept)	Assignee: D.Schafer Due Date: 6/30/2012
	OA5: Perform a material analysis on loose part/foreign material at discovered during FOSAR.	Assignee: M. Mostafa Due Date: **Complete** *(This action is complete. This action is being entered into ActionWay to ensure adequate documentation of performance is provided and the due date is for documentation entry only. Due 5/15/12)*
	OA6: Develop guidance on how to perform oversight of vendors when "proprietary" information prevents the use of third party	Assignee: A. Sistos Due Date: 6/30/12

	reviews	
	OA7: Perform benchmarking of other utilities for "process controls for outsourced modifications" and revise engineering process to come in line with industry best practices.	Assignee: D. Schaferl Due Date: 6/30/12
	OA8: Include within the Unit 3 SG tube failure RCE an analysis of SONGS's retainer bar being an unanalyzed change from a proven design as a cause for the extent of cause review. The intent of this review is to determine if there are other latent scaling issues.	Assignee: J. Osborne Due Date: 5/7/12
	OA9: Develop outgoing OE for issues associated with insufficient Oversight once programmatic deficiencies are identified in MHI report.	Assignee: B. McWey Due Date: 6/30/12

METRICS AND CRITERIA TO MEASURE EFFECTIVENESS OF CAPRS

Based on knowledge gained during the cause evaluation, the Effectiveness Review (EFR) method and qualitative acceptance criteria to be used to measure the CAPRs effectiveness in resolving the root cause is as follows:

Cause Evaluation Element	Description	Assignment Number & Type/Assignee/Due Date/Signature:
Effectiveness review: action being reviewed: CAPR1: Remove the 94 steam generator tubes from service at the retainer bar locations in 2E088 and 2E089 in accordance with SO23-SG-1 Steam Generator Program requirements and the Condition Monitoring and Operational Assessment Report (CMOA). *This will prevent vibration between the retainer bar and tubes from creating a leak. Need to verify retainer bars do not fail due to a weld or break from the vibration.*	EFFR1: At next available SG tube inspection of 2E088 and 2E089 perform a visual inspection of the smaller diameter retainer bars and welds. Conduct a plug inspection to verify no plugs have fallen out. Acceptance criteria: No broken welds or severed retainer bars and no plugs missing. The SG Program requires plug inspection each outage. This inspection verifies both installed and signs of integrity. Therefore, this portion of the effectiveness review is based on that portion of the SG inspection.	Assignee: Al Matheny Due Date: 11/30/2012
Effectiveness review: action being reviewed: CAPR2: Remove the 94 steam generator tubes from service at the retainer bar locations in 3E088 and 3E089 in accordance with SO23-SG-1 Steam Generator Program requirements and the Condition Monitoring and Operational Assessment Report. *This will prevent vibration between the retainer bar and tubes from creating a leak. Need to verify retainer bars do*	EFFR2: At next available SG tube inspection of 3E088 and 3E089 perform a visual inspection of the smaller diameter retainer bars and welds. Acceptance criteria: No broken welds or severed retainer bars	Assignee: Al Matheny Due Date: 10/30/2012

not fail due to a weld or break from the vibration.		

EXTENT OF CAUSE

The Extent of Cause line of inquiry is intended to ensure that corrective actions are developed that are broad enough to prevent a different problem due to the same cause. Extent of Cause is focused on the Root Causes only and determines the extent to which they have, or could, impact other processes, equipment, or human performance.

This RCE (201843216) identifies the mechanistic root cause for Unit 2 SG tube wear at the retainer bars (design). Corrective actions for Unit 2 and 3 (tube plugging/stabilization) bound the failure mechanism and prevent retainer bar to tube wear resulting in a tube leak. MHI is performing an RCE in accordance with their 10CFR50 Appendix B program. That will address the programmatic and technical aspects and implement corrective actions to prevent recurrence. SCE will update this RCE to include a discussion of MHI's programmatic root and contributing causes and initiate actions to close any gaps in or strengthen the oversight program.

SCE has determined that one of the programmatic causes is that MHI did not fully evaluate changes made to a proven design. SCE also purchased the new Reactor Vessel Heads from MHI. SCE is not aware of any changes to the MHI proven design as it applies to SONGS but, as an extent of cause item, that needs to be evaluated. An action to perform this evaluation is included in this report. Further analysis of this as a cause and an extent of cause will be performed as part of the Unit 3 RCE. An action in the cause to corrective action matrix is tracking this.

SAFETY SIGNIFICANCE

This event does not involve an actual failure. The excessive wear was discovered as part of the normal programmatically required inspections of the Unit 2 replacement SGs. The wear was discovered at the first available opportunity. Based on no operational leakage and no structural integrity test failures, the event does not meet the criteria in IMC 0609 Appendix J for LERF increase evaluation. Therefore there is no safety impact.

OPERATING EXPERIENCE

The Recovery and Root Cause team searched industry and site Operating Experience (OE). This included industry data bases and using combinations of key words such as, steam generator, replacement steam generator, new steam generator, wear, tube, leak, retainer bar, and vibration. The data base review included the previous 10 years of INPO IERs and SOERs. The industry review did not identify OE involving retainer bar vibration and interaction with tubes causing tube wear. Based on this review, there was no missed opportunity for SCE to identify and address the potential for retainer bar vibration induced tube wear in our new steam generators. SONGS application of EPRI SG Guidance is in-line with the industry. The OE search did provide insight that tube wear and leaks occur in the industry, including after steam generator replacements. Examples of OE reviewed include:

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--OE19455 (Braidwood) – Two tubes with volumetric flaws due to FME (42% and 27% through-wall)
--OE20361 (Calvert Cliffs) – Small amount of tube wear due to loose parts (FME)
--OE35359 (St. Lucie) – Large number of Anti-Vibration (AVB) wear indications
--OE18651 (Harris) - Steam generator tube leak.
--OE35375 (DC Cook) - A large number of wear indications were identified in the fan bar region.
--OE34946 (TMI-1) - Tube-to-tube contact wear identified during Eddy Current Testing. (SG a once through design and different than SONGS)

--MER PAR 04-019 (Paluel) – Detection of primary to secondary leak on steam generator
--MER PAR 05-034 (Angra) - Indications of tube wear next to anti-vibration bars.
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--932-980101-1 (Darlington) - Steam generator tube leak
--626-990108-1 (Kola) - Steam generator tube crack
--IRS 7957 (Fessenheim) - Circumferential tube crack due to wrongly positioned anti-vibration bars.

Site Operating Experience Review

A review of site OE going back about 8 years did not identify previous problems in SONGS original steam generators with retainer bar vibration induced tube wear. Thus, there was no missed opportunity for SCE to identify and address the potential for retainer bar vibration induced tube wear in our new steam generators. The review did reveal two SONGS RCEs involving equipment design failures involving flow induced vibration.

In both cases, the vendor did not perform or adequately perform vibration analysis. As a result of this review, the SCE Design Change Program will be strengthened by revising SO123-XXIV-1.1 (Document Review Approval and Control) to include a review of the potential for design changes to result in failures due to flow induced vibration, and the tracking of vibration analysis or basis for no action.

SAFETY CULTURE REVIEW

The purpose of this RCE is to determine the tube wear failure mechanism, address the extent of condition, ensure corrective actions are implemented to ensure no additional active tubes are affected and evaluate Edison's oversight of the project to ensure Edison's oversight program provides reasonable assurance of delivery of a quality product. MHI is an Appendix B qualified supplier and as such has their own QA program that meets all of the requirements of Appendix B including criterion XVI for implementation of corrective actions. Because they are a qualified supplier, they will be performing a cause analysis and determining corrective actions to preclude repetition. It is expected that their casual analysis will identify the organizational and programmatic causes associated with the safety culture components. The analysis performed in Attachment 7 identified only potential applicable safety culture aspects since Edison will not be conducting the analysis for MHI and Edison does not have direct access to MHI personnel, training material and records, or Engineering program procedures. SONGS did evaluate Edison oversight activities to determine if there were safety culture aspects that were Root or significant contributors. The assessment determined that there were no safety culture aspects associated with oversight that rise to the level of root or significant contributing causes but identified it as pending in Attachment 8 because it will be reassessed after the MHI report is received.

TRAINING NEEDS ANALYSIS

A training needs analysis was not performed because there were no training elements involved in this event.

WILLFUL VIOLATION ANALYSIS

The potential for deliberate violation of site or NRC requirement was considered in this root cause report. Through investigation and collection of the evidence and facts for this report the team concluded that there was no evidence that warranted action for a "N-WIL" task in the evaluation.

CHANGE MANAGEMENT PLAN

The management sponsor for this report will be given a task to submit an approved Change Management Plan in accordance with procedure SO123-XV-50.7 within 15 calendar days after CARB approval of the RCE with the intent for CARB to review the plan (see corrective action matrix for other action to provide a change management plan).

Attachment 1- Team Charter

Title: Unit 2 Steam Generators

Number: 201843216, Unit 2 – 90% Tube Wear at Retainer Bar

Management Sponsor: Gary Kline – Engineering & Technical Services

Team:
RCE Leader: Dave Schafer – Design Engineering
Qualified Individuals: Eloy Vidales – Performance Improvement
Nuclear Training Division: Mike Ball – Operations Training
Others: Bob Olech – Design Engineering
Kurt Tetzlaff – Operations
Greg Duffy – Industry Consultant

Problem Statement:

Governing Requirement or Standard:

The Steam Generator tubes provides heat transfer capability to allow removal of RCS heat during accident conditions and provides a barrier between the primary and secondary water systems. Technical Specification LCO 3.4.13 requires no pressure boundary leakage or less than 150 gallons per day primary to secondary leakage in any one Steam Generator.

Deviation or Defect:

On February 5, 2012, wear indications greater than [redacted] percent were detected in two locations in each steam generator adjacent to retainer bars during the Unit 2 Cycle 17 refueling outage eddy current examinations.

Consequences of Deviation or Defect:

Steam generator tube wear can cause primary to secondary leakage when through wall holes develop. To prevent future leaks, tubes exceeding wear criteria are isolated by installing a plug on each end. Additional tubes in the area may also require isolation to mitigate future potential leaks. Potential consequences include an increased inspection frequency.

Interim Actions:

Additional inspections and repairs (plugging) were performed. Unit 3 was already shut down for an apparent steam generator tube leak which occurred on January 31, 2012. No other interim actions.

Timeline and Deliverables:

Event Date	Feb. 5, 2012
RCE Assigned	Feb. 8, 2012
RCE Charter with CARB Approval	Feb. 6, 2012
Facts and Working the Analysis (ECFA, Failure Modes, Barrier, etc)	Feb. 17, 2012
Identify Causes and Corrective Actions	Feb. 22, 2012
Identify Extent of Cause, Operating Experience, Safety Components	Feb. 24, 2012
Draft RCE Report	Feb. 24, 2012
CA Buy-in, Sponsor Review/Approve, PI CAPCO Review/Grade	Feb. 28, 2012
Draft Change Management Plan	Feb. 28, 2012
Schedule CARB Review	Feb. 28, 2012
CARB Review/Approval RCE	Mar. 2, 2012
RCE DUE DATE	Mar. 14, 2012

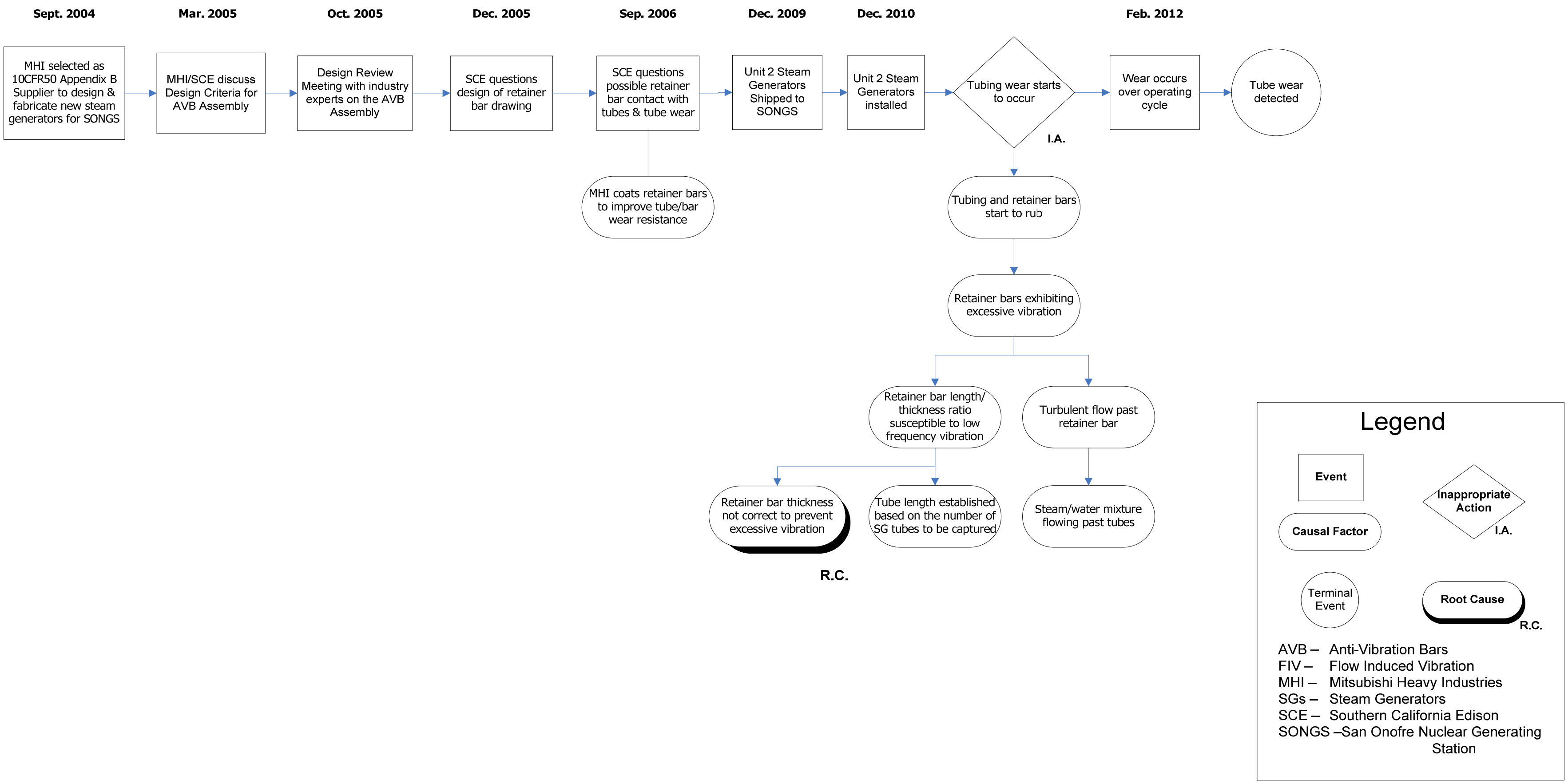
Note: The approved charter with appropriate signatures is attached in Away under NN201843216.

SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL℠ Company

ROOT CAUSE EVALUATION
NN 201843216

Attachment 2 - Event and Causal Factors

SONGS Unit 2 Steam Generator Tube Wear at Retaining Bars Event and Causal Factors



Attachment 3 - Barrier Analysis

CONSEQUENCES (What Happened?)	BARRIER THAT SHOULD HAVE PRECLUDED THE EVENT	OUTCOME (Effective?)	BARRIER ASSESSMENT (What was wrong with the Barrier?)
Wear occurred in tubes adjacent to smaller diameter retainer bars			
a. Retainer bar length increased without corresponding increase in thickness	MHI Design Development Procedures	Not Effective	MHI increased length and did not adequately assess effects of flow induced vibration (FIV).The cause of this will be determined by the MHI cause analysis.
	MHI Design Review	Not Effective	Did not detect. The cause of this will be determined by the MHI cause analysis.
	Edison Document Reviews	N/A	There was no document to review specifically addressing retainer bar vibration or in the change in size of the retainer bar. Had a calculation been performed or an analysis produced, there would have been a document to review.
	Fabrication Procedures	Potentially Failed	Failure to maintain adequate spacing during fabrication could cause stress point on out of position tubes once installed. Not detectable after assembly.
	Edison - Nuclear Oversight Division Audits	N/A	Function to ensure Supplier is following Appendix B to part 50 – Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants (baseline and 2 three-year follow-ups conducted). Not intended to detect proprietary design flaws. The cause of this will be determined by the MHI cause analysis.
	Design Review Meeting with Industry Consultants	N/A	Consultants aware of common industry design issues. Not intended to detect proprietary design flaws.

CONSEQUENCES (What Happened?)	BARRIER THAT SHOULD HAVE PRECLUDED THE EVENT	OUTCOME (Effective?)	BARRIER ASSESSMENT (What was wrong with the Barrier?)
	Use of Industry Operational Experience Data	N/A	No previous OE indicating special attention warranted to retainer bars.
b. Transportation	Installed accelerometers on shipping skids	Effective	Records show no evaluated drops or abnormal accelerations to cause significant internal movement.
c. Installation	Work Package and Installation Procedures	Effective	No abnormal movement or bump during installation to adversely affect internal components.
	Post-Installation Inspection	N/A	Retainer Bar area was inaccessible and no practical method to inspect.
	Post-Installation Testing	N/A	No known method to determine internal vibration prior to power operation.
d. Operational Events	Operating Procedures	N/A	Records show only one significant transient from grid loss event. Rapid reduction in steam flow not likely to cause extended vibration issues.
	Chemistry Procedures	Effective	No abnormalities reported that could cause accelerated wear due to chemical attack.
e. Foreign Object / Loose Part	Manufacturing Procedures	Partially Effective	A small loose part was found on tube support plate #4 and retrieved. No significant wear from part and was not near retainer bar. (201854749)
f. Tube Material Defect	MHI Quality Monitoring	Effective	MHI provided in shop inspection of tube fabrication and review of test reports. No material defects noted to date based on ECT test results.

Attachment 4 - History and System Description

Steam Generators

SONGS Unit 2 is a two loop Combustion Engineering (CE) Pressurized Water Reactor (PWR) which began commercial operation in 1983. The original CE steam generators were replaced in the fall of 2010 with new SGs designed and manufactured by Mitsubishi Heavy Industries (MHI). The replacements, referred to by MHI as model [redacted], incorporate thermally treated Inconel Alloy 690 (I-690TT) tubing, which has demonstrated through laboratory testing and industry experience, superior resistance to stress corrosion cracking as compared with the I-600 tubing used in the original SGs. Other design features include full tubesheet depth hydraulic tube expansion and [redacted] stainless steel trefoil broach tube support plates (TSPs); features chosen primarily to minimize the potential for tube corrosion.

There are [redacted] tubes within each SG, in [redacted] rows and [redacted] columns, in a triangular pitch arrangement. [redacted] to further minimize the potential for inservice stress corrosion cracking in the U-bends. The tube bundle U-bend region is supported by a floating AVB structure consisting of six sets of V-shaped anti-vibration bars (AVBs) between each tube row. The AVBs were fabricated from [redacted] ferritic stainless steel and are equipped with [redacted] end caps. Each AVB end cap is welded to an [redacted] retaining bar. The retaining bars with AVBs attached are supported by [redacted] retainer bars that lock the assembly to the tubes. [redacted] bridges run perpendicular to the retaining bars and retainer bars, and hold the entire assembly together. The AVB structure is not attached to any other steam generator component, other than the tubes.

1. Steam Generator Overview

The main function of steam generators in PWR power plants is to transfer heat from the reactor core and in doing so produce steam. The steam, in turn, drives the main turbine/electric generator to produce electricity. A steam generator consists of a pressure vessel (primary and secondary side), tube bundle, feedwater distribution system, moisture separators and steam dryers. The steam generators are connected to the reactor coolant, main steam, feedwater and blowdown systems piping. Within the secondary side of the pressure vessel, a bundle of U-tubes, typically made of Inconel, provides surface area required for heat exchange between the reactor coolant and the feedwater. Reactor coolant flows through the tubes and causes the feedwater that is in contact with the exterior surface of the tubes to boil, generating saturated steam. After passing through the moisture separators and steam dryers, essentially dry, saturated steam leaves the steam generator on its way to the high-pressure turbine.

2. Significance of the Steam Generators

In the PWR plant, there are three boundaries preventing radioactive material from being released to the environment – nuclear fuel cladding, reactor coolant pressure boundary and the containment structure housing the Nuclear Steam Supply System (NSSS). The steam generator primary side (channel head) and heat transfer tubing are a part of the reactor coolant pressure boundary. In addition to being a part of the pressure boundary, the steam generators are a part of the safe shutdown system and are required to remain operable for heat removal during certain plant upset and postulated accident conditions. Because of the safety significance of the steam generator tubing, the NRC places a high priority on licensees ensuring the integrity of the tubes. In this respect, the NRC states in the USNRC Fact Sheet dated January 2004 that:

"The NRC places a high priority on ensuring that steam generator tube degradation is carefully monitored through inspections, strict repair criteria and the monitoring of water chemistry to detect radiation leaking from the primary to the secondary side of the plant. In addition, NRC regulations establish requirements for steam generator tube integrity. Tubes must have an extremely low probability of abnormal leakage and must be periodically inspected and tested."

"To obtain an operating license, applicants must show that the consequences of a steam generator tube rupture would not exceed the NRC's conservative limits for offsite radiological doses (described in the agency's regulations in Title 10 of the Code of Federal Regulations, Part 100). Plant operators also are required to have emergency procedures for mitigating steam generator tube ruptures and leaks."

"Once a plant is in service, its operator is required to inspect and repair or remove from use all tubes found to contain flaws exceeding certain limits. Each plant's technical specifications describe the frequency and scope of these inspections and tube repair limits. There are also operational leakage limits to ensure that if any of the tubes leak, the plant will be shut down quickly. Existing regulations have been effective in providing reasonable assurance of protecting public health and safety. This has been accomplished through evaluations of individual plants experiencing significant amounts of tube degradation. These evaluations have, in some instances, resulted in more frequent inspections at mid-operating cycle."

3. Tube Inspections

Because of the safety significance of the steam generator tubing, Edison places a high priority on ensuring the integrity of the steam generator tubes. The steam generators are monitored during operation for primary-to-secondary leaks and are inspected on a regular basis during refueling outages. The SONGS technical specifications and the Steam Generator Program define the requirements for this monitoring and inspecting and provide the acceptance criteria. The primary inspection method for the tubing used during outages is eddy current testing (ECT). In eddy current testing, a probe is inserted through the tubes and disturbances of the electric field caused by anomalies within the tube wall can be interpreted to determine location, type and magnitude of tube degradation. In a typical inspection, all tubes are inspected in each steam generator. Frequently, the tubes are inspected with multiple types of probes in the areas of special interest, such as the U-bend or the tubesheet area.

4. Tube Repair

When a steam generator tube is degraded to a degree that requires repair, three repair methods are generally currently used. The first one is to completely remove the tube from service by plugging it at both ends. This is the most commonly used repair method. The second method uses a short length of tubing to span the degraded portion of the tube. This method is known as sleeving and is only feasible if the degraded region is accessible for sleeve installation. Sleeves are more costly to install than plugs, but do allow the tube to remain in service and therefore can extend the economic life of the steam generator by maintaining the heat transfer surface area. Finally, some plants have performed the necessary safety analysis and obtained NRC approval to keep degraded tubes in service until a higher degree of degradation occurs. Known as alternate repair criteria, this has not been cost-effective for the SONGS steam generators. Besides, the necessary safety analysis can only be successfully performed for a narrowly defined subset of tube degradation types.

5. Steam Generator Replacement

When the steam generators can no longer perform their safety function due to excessive loss of the heat transfer surface area as a result of progressive tube plugging and an increased probability of loss of tube integrity, they must be replaced in order for the power plant to continue operation. In addition, replacement of the steam generators has typically been performed when the utility concluded that they were reaching their economic end-of-life. This occurs when forecasts of maintenance and repair costs exceed the amortized benefits of the reduced costs achievable with the replacement steam generators. Included in the costs of continuing to operate the original steam generators is the reduction in the plant megawatt output that occurs as tubes are removed from service. Typically, the steam generators are manufactured with approximately 10% excess tubes to allow some to be removed from service without affecting plant performance, but that excess is generally used up already for those plants considering replacement.

6. Design and Operating Parameters

The new steam generators are designed as an in-kind replacement in terms of function. As such, the design pressure and temperature are the same as the original pressure and temperature requirements. The physical parameters such as the number of tubes are dictated by the desire to maximize the heat transfer surface area. The operating parameters are slightly different than the old steam generators as a result of the use of a different tubing material and differences in the design of the internals.
The SONGS steam generators are qualified to operate in the T_{hot} range from [redacted] and at a target reactor coolant flow rate of [redacted] of the previous steam generator design value, which is approximately the flow rate at which the steam generators were operating prior to replacement. The replacement steam generators are designed to operate with the same variable water level program and with the same water level control set points. The new steam generators operate with a slightly higher circulation ratio (approximately 3.3 versus 3.2) at full power. The primary side volume is slightly greater due to a larger internal volume of the tube bundle. The secondary side masses of the old and new steam generators are approximately the same at full power.

Table 1 provides a comparison of the major design and operating parameters. All numerical values in the table are per steam generator, where applicable.

7. Design Features

The old and new steam generators are both vertical U-tube steam generators. Consequently, many design features are common to both. However, lessons learned from performance of the old steam generators and of the other steam generators in the industry, including those fabricated by MHI, were incorporated into the design of the SONGS replacement steam generators and their fabrication methods. Design changes were made to address operating experiences to enhance the overall reliability and maintainability. This included the use of forgings for the steam generator shell, instead of plates, improved materials for tubing, tube supports and feedwater distribution system, improved design of the tube-to-tubesheet joints, tube supporting structures, feedwater ring and the channel head, as well as inclusion of the integral steam flow limiter. The new steam generators have improved access provisions for maintenance and inspections, and improved access to the internal components.

During fabrication, strict quality controls were in effect to ensure as best as possible execution of the improved design. All this was done with the following goals in mind:

- To minimize wear of the steam generator tubes,
- To eliminate susceptibility to inter-granular attack (IGA) and stress corrosion cracking of the steam generator tubes,
- To eliminate general corrosion within the steam generators.

Each steam generator consists of several major components, which include the upper and lower shell with transition cone and elliptical upper head, tube bundle, tube supports, tubesheet and channel head, feedwater distribution system, moisture separation equipment and access provisions. The elevations of the level taps are such that the level setpoints are the same in terms of percentage of the narrow and wide range spans. The elevations and orientations of other instrument taps are similar and are such that the existing sensing lines can be easily reconnected. The locations of the large nozzles (i.e., reactor coolant, main steam and feedwater) are identical to the previous locations to eliminate the need for modification of the major piping. The new steam generators are supported in the same manner utilizing the existing sliding base, key brackets and snubber assemblies.

7.1 Upper and Lower Shell

In the new steam generators, forgings are used for fabrication of all pressure boundary parts (e.g., channel head, lower and upper shell, major nozzles, etc.), in order to minimize the number of pressure boundary welds. The previous steam generator shell is fabricated from plates and includes both circumferential and longitudinal welds. The upper shell diameter is unchanged; the lower shell diameter is approximately 2 inches larger than the previous design.

In the new steam generator, a flow-limiting device, consisting of seven venturi nozzles with a throat ID of [redacted] inches, is installed in the steam outlet nozzle integral to the upper head, in order to reduce the rate of mass/energy release into the containment during a postulated Main Steam Line Break (MSLB) inside containment. It also reduces the loads on the steam generator internals during such an event. The previous design does not include an integral steam flow limiting device.

In the new steam generator, the blowdown provisions are in a form of a peripheral open channel on the secondary side of the tubesheet, with the [redacted] blowdown nozzle attached to the tubesheet. The channel provides for complete drainage of the secondary side, so the blowdown nozzle serves also as a secondary side drain nozzle. The previous design includes 2-inch carbon steel internal blowdown piping with a 2-inch blowdown nozzle attached above the tubesheet.

7.2 Tube Bundle

The tube bundle is designed to provide the heat transfer rate equivalent to the previous design. In the new steam generator, the number of the heat transfer tubes is [redacted] as compared to 9350 in the old steam generators. The new tube bundle is approximately 17 inches taller. The tube size maintains the [redacted] outside diameter (OD). However, due to the increased length and the number of tubes, the nominal heat transfer surface area is [redacted] whereas the previous surface area is approximately 105,000 ft^2. The nominal tube wall thickness was reduced from 0.048 inches to [redacted] inches as a result of using a higher strength material. The tube pitch is [redacted] triangular, the same as the previous pitch.

<u>Tubing material</u>
The tube material is thermally treated Alloy 690 (Alloy 690 TT). The previous tube material is mill annealed Alloy 600 (Alloy 600 MA). Alloy 690 TT has been under development since the early 1970s, and based on extensive industry-wide tests, has been determined to be the material of choice for use in the replacement steam generators industry-wide. Both laboratory testing and operational experience have proven that Alloy 690 TT is much more resistant to IGA and stress corrosion cracking in both primary and secondary water environments than Alloy 600 MA. No tube degradations due to stress corrosion cracking have been reported to date in any MHI steam generators using Alloy 690 TT as tubing material.

<u>Tube-to-Tubesheet Joint</u>
The primary function of the tube-to-tubesheet joint is to provide a leak tight barrier between the primary and secondary sides of the steam generator. The tubes are seal-welded to the tubesheet and then hydraulically expanded along the full thickness of the tubesheet. The secondary side tube-to-tubesheet crevice is minimized by locating the expansion transition zone as close as practical to the secondary face of the tubesheet. Each tube also has a one-step mechanical roll near the primary face of the tubesheet to ensure proper joint pullout strength and leakage resistance, and to reduce tensile residual stresses near the tube-to-tubesheet weld. The old steam generator tubes are seal-welded to the tubesheet and explosively expanded.

7.3 Tube Supports

The steam generator tubes are supported by tube support plates in the straight-leg region and by the anti-vibration bar (AVB) structure in the U-bend region.

<u>Tube Support Plates</u>
In the RSG, [redacted] tube support plates with broached, trefoil, flat-land tube holes are used. The tube support plates are made of [redacted] ferritic stainless steel. The tube support plates are designed to reduce the tube-to-tube support plate crevice area while providing

for a maximum steam/water flow in the open areas adjacent to the tube. Flat-land tube-to-tube support plate contact geometry provides additional margin for dryout. Materials are selected to minimize the potential for tube wear and denting due to tube support plate corrosion. The old steam generator tubes are supported by egg-crate grid type tube supports, constructed from straight bars that are sized to fill the interstitial space between the tubes. The egg-crate bars are made of carbon steel.

AVB Structure

Six sets of V-shaped AVBs, providing up to 12 support points per tube, are installed in the U-bend region to provide support in the region where the tubes are most susceptible to degradation due to wear due to flow-induced vibration. During fabrication, the thickness of the AVBs and the tube-to-AVB gap were tightly controlled. The 12 tube support points provide redundancy, so that all the tubes remain fluid-elastically stable even if some of the support points are inactive. The AVBs are nearly perpendicular to the centerline of the tubes at all 12 support locations to provide support while minimizing the tube-to-AVB contact length (to minimize the potential for local corrosion and wear). These features of the U-bend support system provide significant margin against flow stagnation, corrosion, and tube vibration. In the old steam generators, tube U-bend configuration includes two 90-degree bends on either side of a horizontal run, and the support system includes relatively wide diagonal batwings and vertical strips for supporting the horizontal run of the bends, all made of carbon steel.

7.4 Tubesheet and Channel Head

The previous channel head design included a tubesheet center support cylinder (stay cylinder), which permits the tubesheet thickness to be minimized. In the new steam generators, the stay cylinder is eliminated and the tubesheet is thicker, as it is supported only by a structural divider plate. This design approach allows for more heat transfer tubes and eliminates the “cold zone” in the center region of the tube bundle, which is considered a likely contributor to tube wear in the bundle U-bend central region. The tubesheet is a single piece forging with integral weld preparations. The reactor coolant volume is approximately 5% more than the previous volume, but still within the allowable limit dictated by the containment building flooding analysis.

The channel head has a flat bottom and the outlet plenum is self-draining. The inlet and outlet nozzles contain integral grooves for installation of the nozzle dams with quick locking pins and inflatable seals for primary side inspection and maintenance operations. The design also includes provisions for preventing reactor coolant spillage during manway cover removal. The reactor coolant inlet nozzle design incorporates a flow limiting orifice in order to offset the effect of increased number of tubes (in terms of the primary side flow resistance) on the reactor coolant flow rate, and maintain this rate within the allowable limits. The previous design does not include the provisions mentioned above.

7.5 Feedwater Distribution System

Feedwater is introduced into the steam generator through a feedwater nozzle located on the upper shell. The nozzle contains a welded [redacted] thermal sleeve, which minimizes the impact of large temperature transients on the nozzle and shell during cold auxiliary feedwater injection. The feedwater ring design includes [redacted] extending above the elevation of the feedwater [redacted]. This feature eliminates thermal stratification in the feedwater nozzle and the connecting feedwater piping, and prevents the feedwater ring from draining on loss of main feedwater flow, thus minimizing the potential for water hammer. The previous design employs a thermal sleeve and a distribution box, and does not include features preventing thermal stratification or water hammer on loss of feedwater flow.

The feedwater ring is designed to uniformly distribute the feedwater flow around the upper shell. Special perforated nozzles are spaced around the top of the feedwater ring to distribute the feedwater into the upper shell recirculating water pool without impinging on any internals. The purpose of the perforated nozzle design is to capture loose parts that may enter the steam generator with feedwater and provide for feedwater flow pressure reduction. The nozzle location prevents the feedwater ring from draining, thus eliminating the potential for water hammer on steam generator water level decrease. The previous design utilizes “J-nozzles” to reduce the potential for water hammer on steam generator water level decrease.

The new feedwater ring is fabricated from [redacted] steel with [redacted] fittings, which provide increased resistance to erosion/corrosion. The original feedwater ring is fabricated from carbon steel, which has a much lower resistance to erosion/corrosion.

7.6 Moisture Separation Equipment

Moisture separation equipment includes the moisture separators and steam dryers.

<u>Moisture Separators</u>
The new design includes [redacted] high performance centrifugal moisture separators welded to the lower deck plate. The moisture separators use swirl vane, riser separating, and outlet orifice design features, and are made of [redacted] steel resistant to erosion/corrosion. The OSG design includes 212 moisture separators of a smaller diameter made of carbon steel, which are bolted to the lower deck plate.

<u>Steam Dryers</u>
The design includes [redacted] banks of single-tier dryers with perforated panels on the inlet side and layers of tightly packed dryer vanes inside each bank. The single-tier dryer bank spacing and the total length of the banks provides much more separating capacity than is available in the previous dryer arrangement. Steam dryer performance is further

enhanced through the use of Peerless double-pocket high-capacity dryer vanes. Drain pipes carry the captured water from the dryers downward into the recirculating pool. The previous design includes a set of 162 steam dryers that have much smaller moisture separation capacity.

7.7 Access Provisions

The new design includes [redacted] primary manways on the channel head, and [redacted] secondary manways on the upper shell. The new design also includes [redacted] handholes located on the extension ring just above the tubesheet and [redacted] handholes located on the transition cone just above the uppermost tube support plate, and [redacted] inspection ports. Two inspection ports, 180-degrees apart, are located above each of the six lower tube support plates. Each handhole and inspection port provides access to the tube bundle via a sleeve and a closable penetration in the wrapper. The previous design included two 16-inch manways on both the primary and secondary sides and two 6-inch handholes on the secondary side above the tubesheet. The old steam generators do not have shell penetration provisions for upper bundle or individual tube support inspection access.

The new design offers more upper shell space for access via the use of an elliptical upper head, instead of a hemispherical head. Access to the bottom and top of the steam dryers and the steam nozzle is provided via hinged hatches. The previous design does not provide such access.

The downcomer annulus at the feedwater nozzle orientation is much wider at the top than in the previous design, thereby facilitating access to the nozzle and feedwater ring. The access above the feedwater ring is provided via an annular space between the lower moisture separator deck plate and upper shell. The feedwater ring is equipped with two closable access ports, 180 degree apart, for remote inspection and foreign material retrieval. The old design annulus above the feedwater ring is of a smaller size, thereby restricting accessibility for maintenance or inspection. The feedwater ring itself does not have any access provisions.

Access to the tube bundle U-bend region is provided via hinged hatches. Also, the design of the moisture separators permits direct access of video equipment to the tube bundle U-bend for remote inspections. The previous design does not provide such access. The previous design included a manway with a bolted cover for access to the tube bundle U-bend region.

Table 2 provides a comparison of the access provision differences.

7.8 Water Level Control

The level tap elevations are such that the water level control ranges and set points are the same in terms of the spans and the percent (%) of the narrow and wide range spans. The normal water level for full-load operation is 574 inches above the secondary face of the tubesheet for both designs. The new design differs in that it includes the mid-deck plate, located within the water level control range, which introduces an internal pressure drop due to steam flow. The effect of the mid-deck plate pressure drop on level measurement is accounted for in the calibration of the narrow-range level instrumentation.

The ability of the Feedwater Control System (FWCS) to control steam generator level, and the Steam Bypass Control System (SBCS) and Atmospheric Dump Valves (ADVs) to control pressure has been reviewed. The setpoints and tuning parameters of these systems do not require change.

Table 2 provides a comparison of the level tap elevation differences.

7.9 Physical Interfaces

The replacement steam generators are designed as an in-kind replacement in terms of fit and form, intended for installation without any, or minimal, permanent modifications to the plant systems, structures or components. As such, the envelope dimensions are the same dimensions with the exception of the lower shell diameter, which is approximately 2 inches larger. Also, the number, orientation and elevation of the nozzles is the same with the following exceptions:

The new steam generator has one wide-range lower level tap on the extension ring, whereas the previous design has this tap installed on the hand hole cover.

The orientation of two narrow-range level taps is different to avoid interference with one of the lifting trunnions for installation.

The new steam generator has one secondary side sampling tap, one dry layup nozzle, one wet layup nozzle and one recirculation nozzle on the upper shell and head, whereas the previous design has only the sampling tap. The additional nozzles are for potential future use and will be initially capped.

The new steam generator has one blowdown/secondary drain nozzle located in the tubesheet, whereas the previous design has the nozzle on the lower shell above the tubesheet. The location of the blowdown nozzle is slightly lower from the previous design. The total operating weight of the new steam generator is slightly greater than the previous weight (by approximately 43,000 lbs.).

Table 2 provide a comparison of the outline dimension and weight changes.

Table 1 - Comparison of Design/Operating Parameters

Parameter	***OSG***	***RSG***
General		
Thermal rating, MWt	1729	[redacted]
Number of Tubes	9350	
Heat Transfer Area, ft^2	105,000	
UA, Btu/hr °F	1.5E8	
Tubes Outside Diameter, in.	0.750	
Tube Wall Thickness, in.	0.048	
Tube Pitch, in.	1.0 triangular	
Tube Plugging Margin, %	8	
Primary Side		
Design Pressure, psia	2500	
Design Temperature, °F	650	
Operating Pressure, psia	2250	
Operating Temperature (T_{hot}), °F	611.2	
Operating Temperature (T_{cold}), °F	553.0	
Reactor Coolant Flow (at cold leg temperature), gpm	198,000	
Reactor Coolant Volume, ft^3	1895	
Secondary Side		
Design Pressure, psia	1100	
Design Temperature, °F	560	
Operating Pressure (@100% power), psia	900	
Operating Temperature (@100% power), °F	532	
Steam Flow, lb/hr	7,414,000	
Steam Moisture Content, %	<0.20	
Feedwater Temperature, °F	445	
Blowdown Flow, lb/hr	151,000	

Note Tube Pitch in the u-bend region of the RSGs varies due to indexing

Table 2 – Comparison of Physical Features

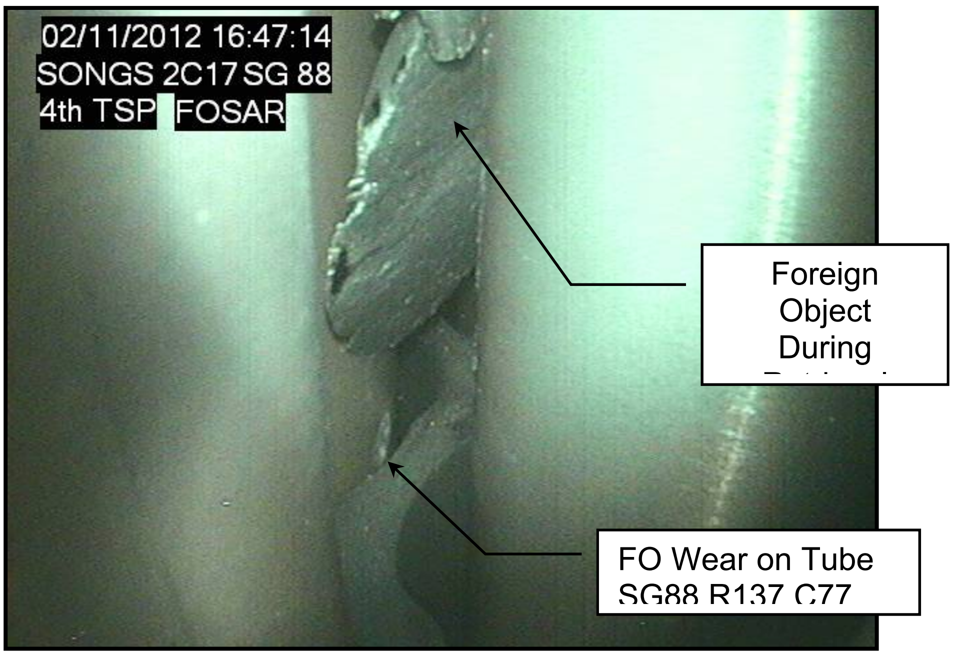
Access Provisions	***OSG***	***RSG***
Primary Manways, Qty - ID, in.	2 - 16	[redacted]
Secondary Manways, Qty - ID, in.	2 - 16	
Secondary Handholes, Qty - ID, in.	2 - 6	
Secondary Inspection Ports, Qty - ID, in.	----	
Level Tap Elevations(1)	OSG	
Wide Range Level Lower Tap, in.(2)	19.5	
Narrow Range Level Lower Taps, in.(2),(3)	315.3	
Top of the Tube Bundle, in.	381.0	
Top of the Feedwater Ring, in.	393.6	
Normal Water Level, in.	438.6	
Wide/Narrow Range Level Upper Taps, in. (2)	496.1	
Outline Dimensions	OSG	
Overall Height (including support skirt), in.	786	
Upper Shell OD, in.	264.125	
Lower Shell OD, in.	172.375	
Weights	OSG	
Dry, lbm	1,242,366	
Flooded, lbm	1,971,840	
Operating, lbm	1,505,437	

Notes:

1. *All elevations are nominal and are from the top of tubesheet; the nominal elevation of the top of the tubesheet from the bottom of the support skirt is 135.25 in. for the OSG and* [redacted] *in. for the RSG.*
2. *The level tap elevations are at the reference (cold) condition.*
3. *The narrow range level lower tap elevation corresponds to its centerline intersection with the transition cone ID.*

Attachment 5 - Foreign Object Evaluation NN 201854749

ECT showed tube wear at a location other than an AVB, TSP, or free span tube to tube. The cause of the wear was determined to be a foreign object. The object was approximately 0.75 inches in diameter by 0.1 inches thick. [redacted]



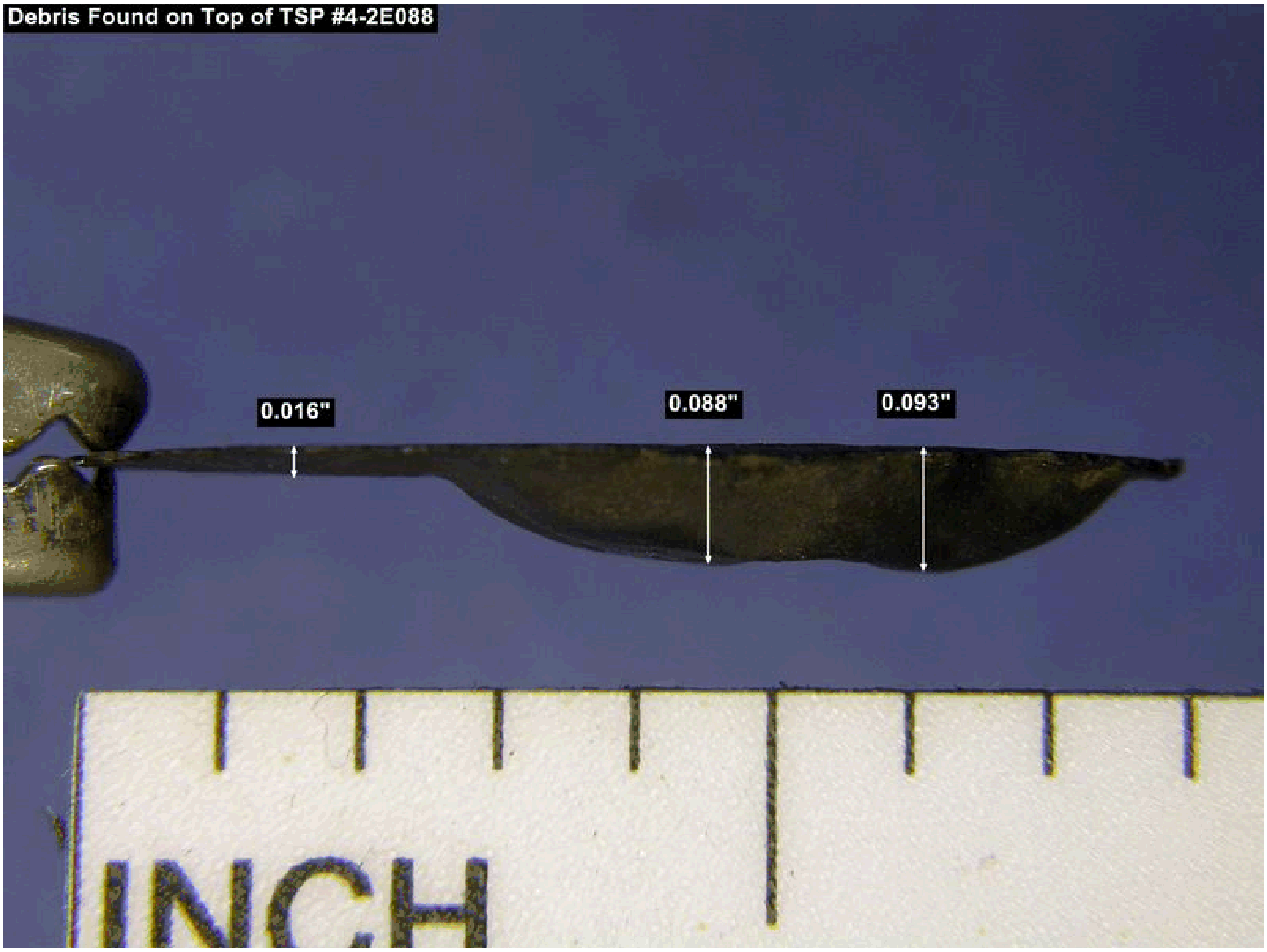
Debris Analysis

The debris was photographed and the overall dimensions were measured. The debris was examined under optical microscope. Scanning Electron Microscope (SEM) and Energy Dispersive X Ray Spectroscopy (EDS) were also performed on surfaces of the debris (top and bottom surfaces) after acetone cleaning. Thereafter, a longitudinal cross section was prepared through the midsection of the debris. The cross section was examined in the as etched condition to reveal the micro structure. EDS analysis was performed on the core of the debris for comparison to the EDS performed on both of the surfaces. Micro-hardness measurements were also performed on the cross section.

Results:

The overall appearance and dimensions of the debris are illustrated in two next photographs.


Debris Found on Top of TSP #4-2E088
Weld Metal - 1
Weld Metal - 2
0.518"
0.829"



The optical microscope examination revealed the debris as a weld metal of which a portion (identified in the photos as Weld Metal #1) had flowed into a crevice and a rounded portion (identified as Weld Metal #2). The nominal thickness of the Weld Metal #1 was measured as 0.016" and it tapers down at the extremities.

Summary and Conclusion:

The analysis identified the debris as excess weld metal part of which had flowed into a crevice slightly wider than 0.016". [redacted]

Attachment 6 - Unit 2 Eddy Current Testing (ECT) Summary

Eddy Current Testing Methodology

Eddy-current testing uses electromagnetic induction to detect flaws in conductive materials such as the tubes in the steam generator. A circular coil carrying current is placed inside the subject tube. The alternating current in the coil generates changing magnetic field which interacts with test specimen and generates eddy current. Variations in the phase and magnitude of these eddy currents are monitored using a second 'receiver' coil, or by measuring changes to the current flowing in the primary 'excitation' coil. Variations in the electrical conductivity or magnetic permeability of the tube material, or the presence of any flaws, will cause a change in eddy current and a corresponding change in the phase and amplitude of the measured current. This is the most widely used method for inspecting steam generator tubes. ECT results did not indicate continuous contact between the retainer bars and the tubes, which would be an indication of movement of the AVB Assembly. The results are tabulated to provide a percentage of through wall depth (%TW). In addition to ECT, in-situ pressure testing was performed on the tube with the most wear with no failure.

Unit 2 Eddy Current Findings

Table 1 – Wear Indication Summary

LOCATION	2E088		2E089		TOTALS	
	Tubes	Indications	Tubes	Indications	Tubes	Indications
Anti-Vibration Bars	595	1,757	804	2,591	1,399	4,348
TSPs	180	225	119	139	299	364
Retainer Bar	2	2	4	5	6	7
Foreign Object	2	2	0	0	2	2
Free-span (Tube to Tube)	0	0	0	0	0	0

Table 2 – Bobbin Probe Wear Depth (% TW) Maximum per Tube
(Located at AVB and TSP only)

Steam Generator	None	0-10%	10-19%	20-34%	>35%	Sum
2E088:	8,645	600	406	74	2	9,727
2E089:	8,398	768	496	65	0	9,727
TOTALS	17,043	1,368	902	139	2	19,454

Table 3 – Retainer Bar Wear

Steam Generator	Row	Col	Maximum Depth (%TW)
2E088	124	48	47
2E088	125	49	58
2E089	118	44	30
2E089	119	133	90
2E089	120	132	28
2E089	120	132	30
2E089	127	127	38

Table 4 – Foreign Object Wear

Steam Generator	Row	Col	Maximum Depth (%TW)
2E088	136	76	29
2E088	137	77	33

Foreign Material

The straight leg portion of the tube bundle has seven tube support plates approximately equally spaced between the tubesheet and the U-bend region. Steam generator 2E088 had a foreign object at the middle support plate between adjacent tubes. The foreign object (0.75 inches in diameter by 1/8 inch thick) has been removed (NN# 201854749). See Attachment 5 for actual object dimensions. [redacted] As such, the object was most likely introduced during fabrication because it was too large to travel through feed ring nozzles. Based on the size and location, this object is not cause related to the tube wear at retainer bar locations.

There were no other loose parts detected by ECT or by FOSAR at the Top of Tubesheet. The peripheral tubes examined at TTS using rotating probes also provided no indications. In addition, visual inspections that were performed on the U-bend section and at the upper tube support plate did not reveal any additional loose parts. Thus, no loose parts remain in the Unit 2 steam generators.

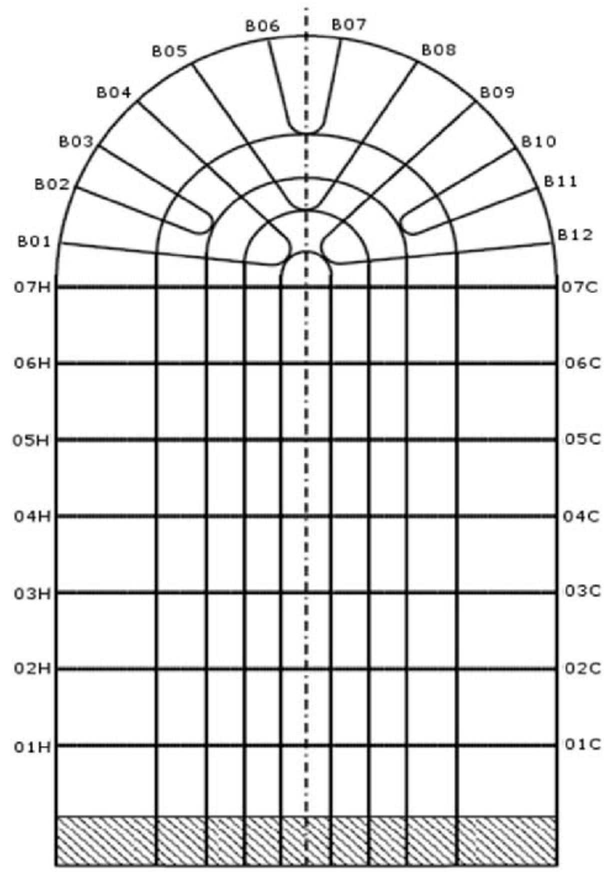
In-Situ Pressure Testing

The single tube (2E089, row 119, column 133) with 90% through wall leakage at the retaining bar location was selected for an In-situ pressure test. This test is performed to ensure that the tube would not have ruptured in the event of a steam line break.

The test results indicate no leakage occurred at the structural test pressure and met all acceptance criteria per EPRI guidelines.

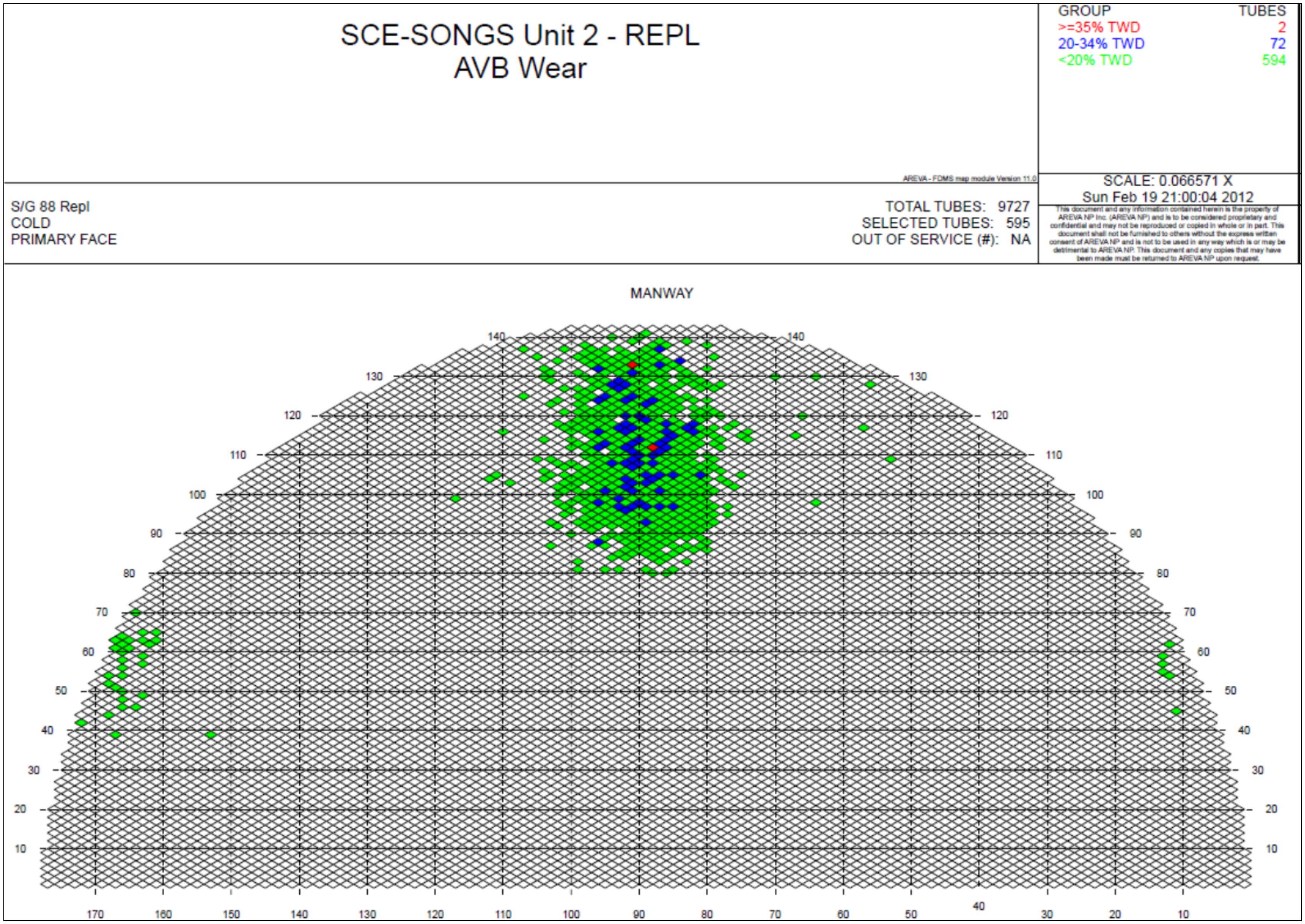
Steam Generator Support Locations:

Hot Leg TSP Locations =	01H to 07H
Cold Leg TSP Locations =	01C to 07C
AVB Bar Ends =	B01 to B12



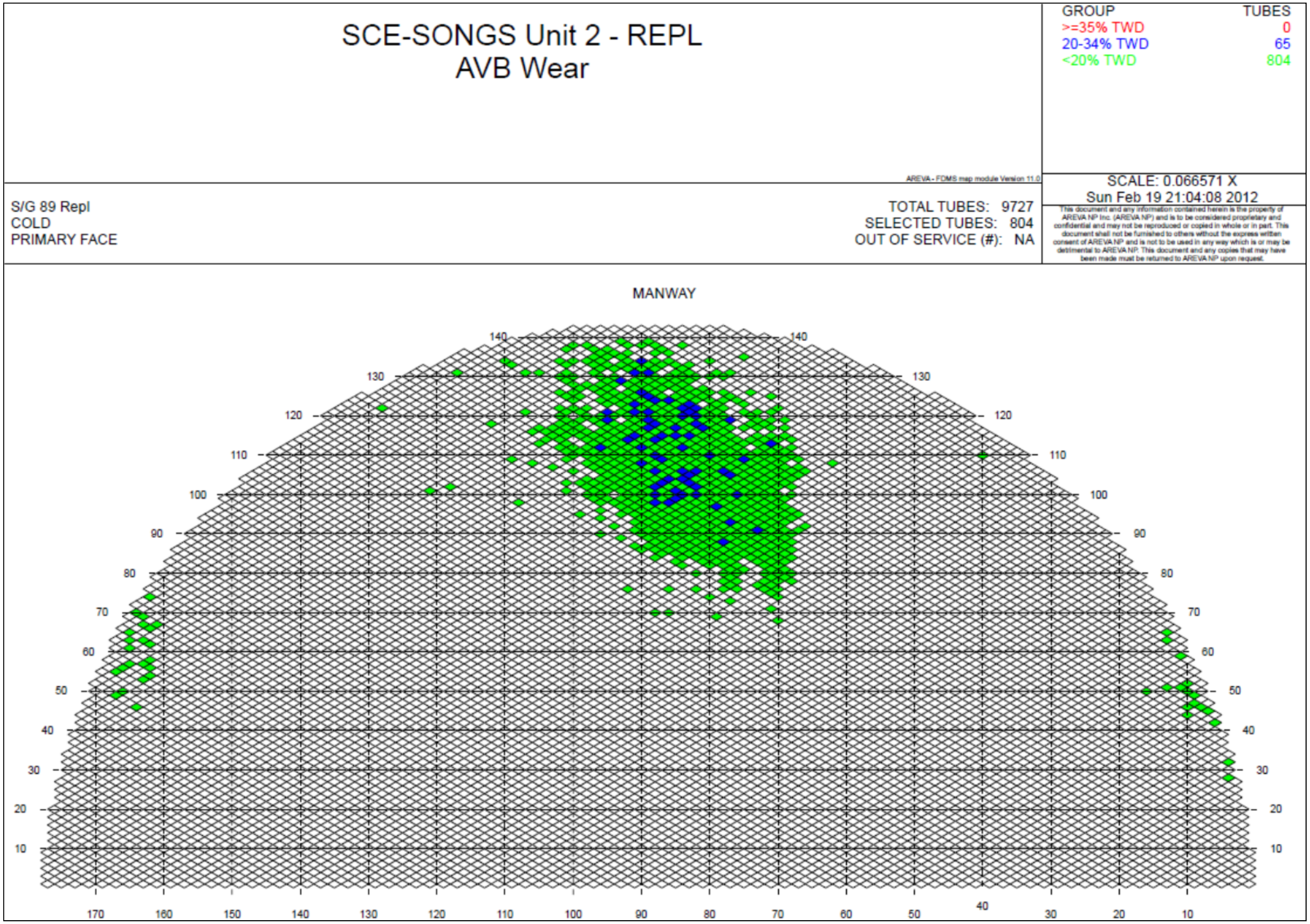
SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL℠ Company

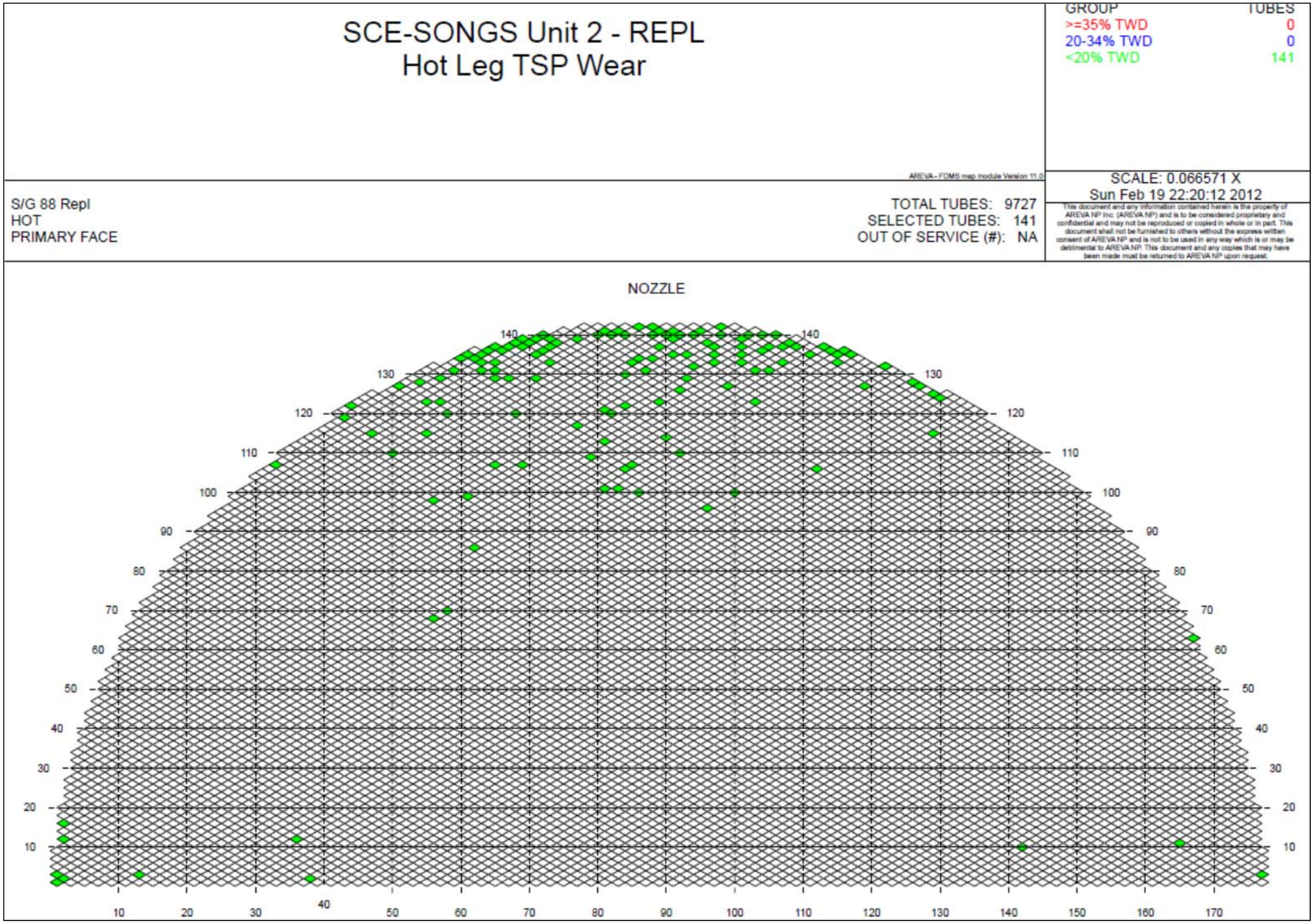
ROOT CAUSE EVALUATION
NN 201843216



SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL℠ Company

ROOT CAUSE EVALUATION
NN 201843216




SCE-SONGS Unit 2 - REPL
Hot Leg TSP Wear
GROUP TUBES
>=35% TWD 0
20-34% TWD 0
<20% TWD 141
SCALE: 0.066571 X
Sun Feb 19 22:20:12 2012
S/G 88 Repl
HOT
PRIMARY FACE
TOTAL TUBES: 9727
SELECTED TUBES: 141
OUT OF SERVICE (#): NA
NOZZLE

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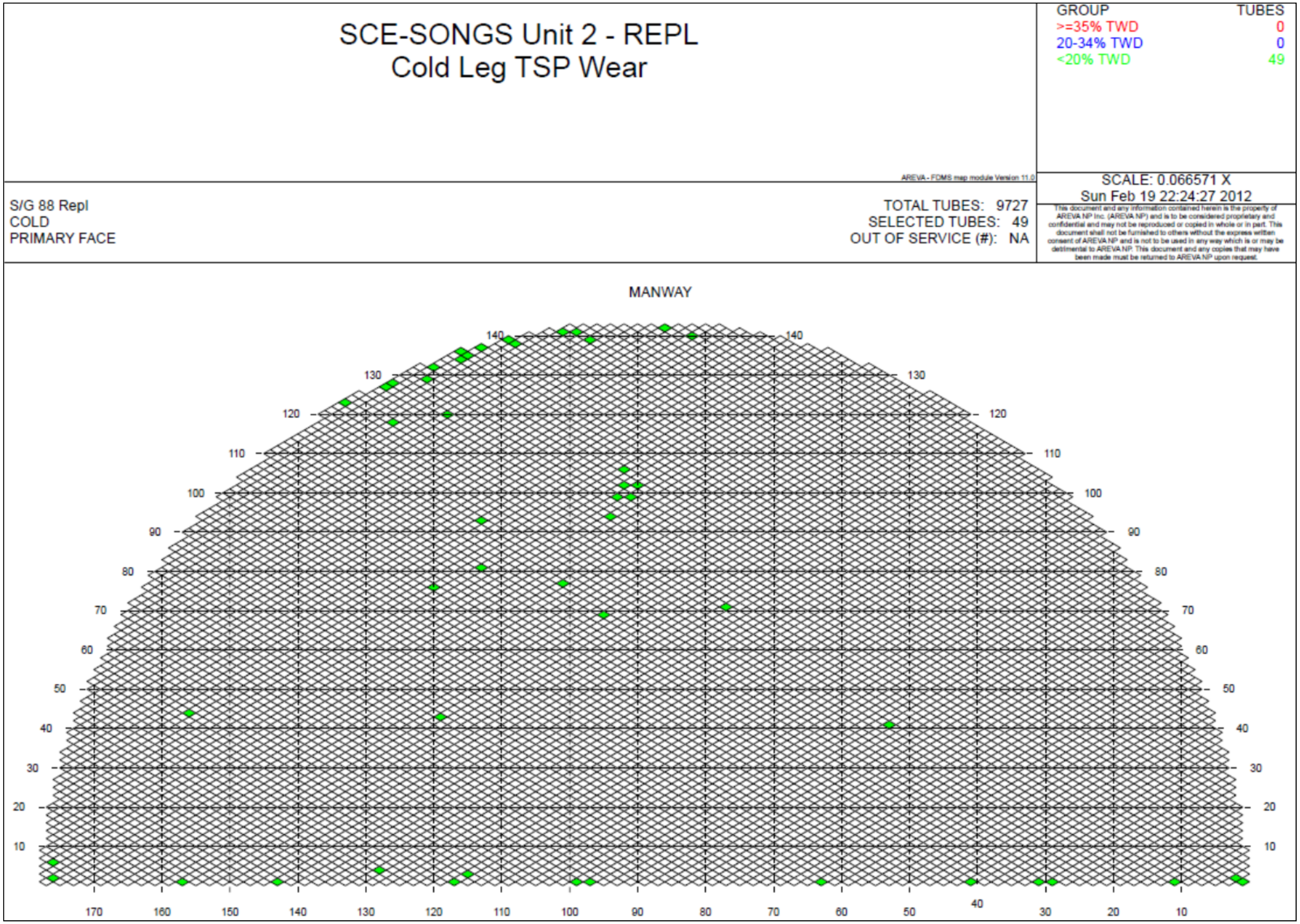
ROOT CAUSE EVALUATION
NN 201843216



SOUTHERN CALIFORNIA EDISON
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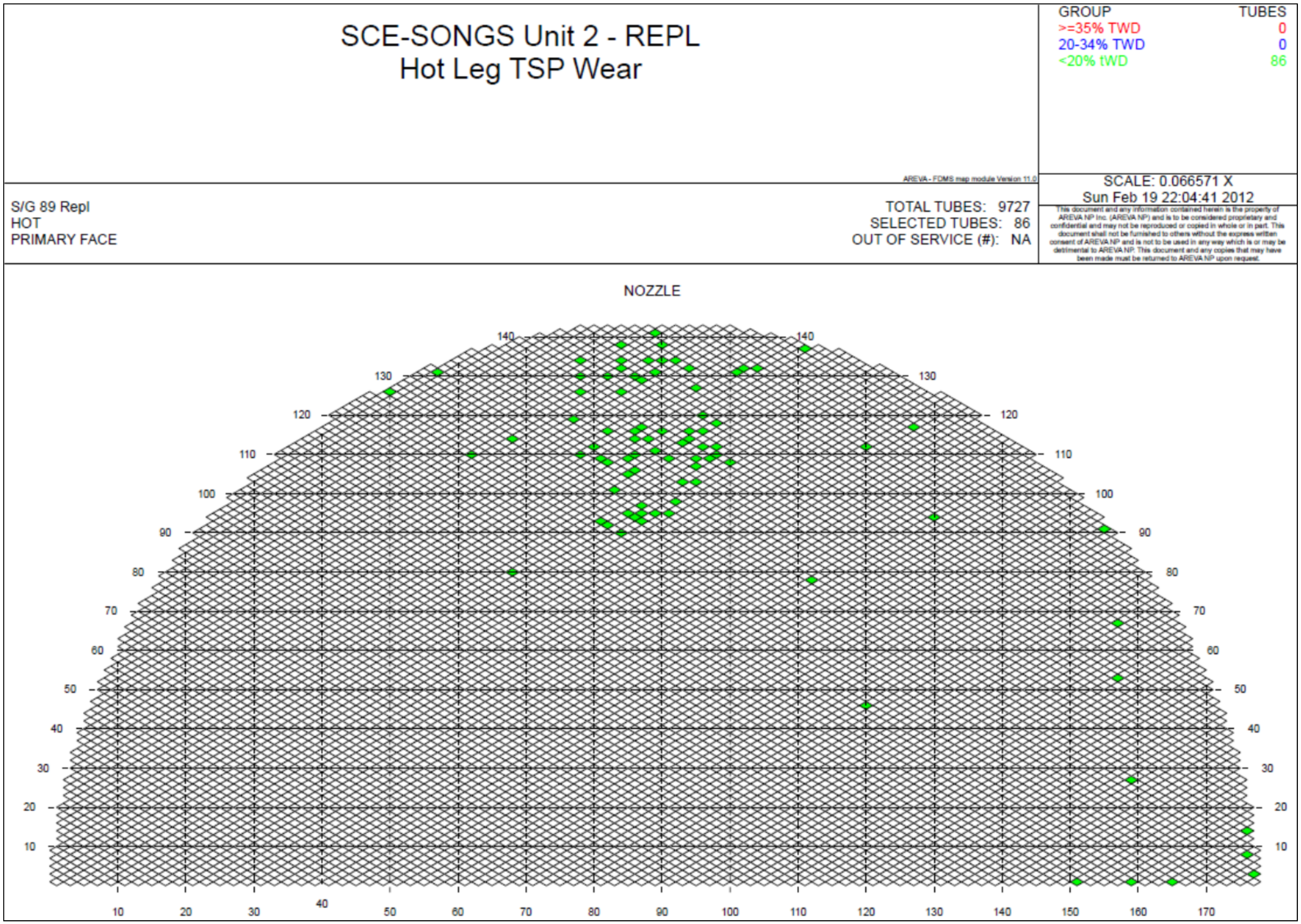
ROOT CAUSE EVALUATION
NN 201843216



SCE-SONGS Unit 2 - REPL
Cold Leg TSP Wear

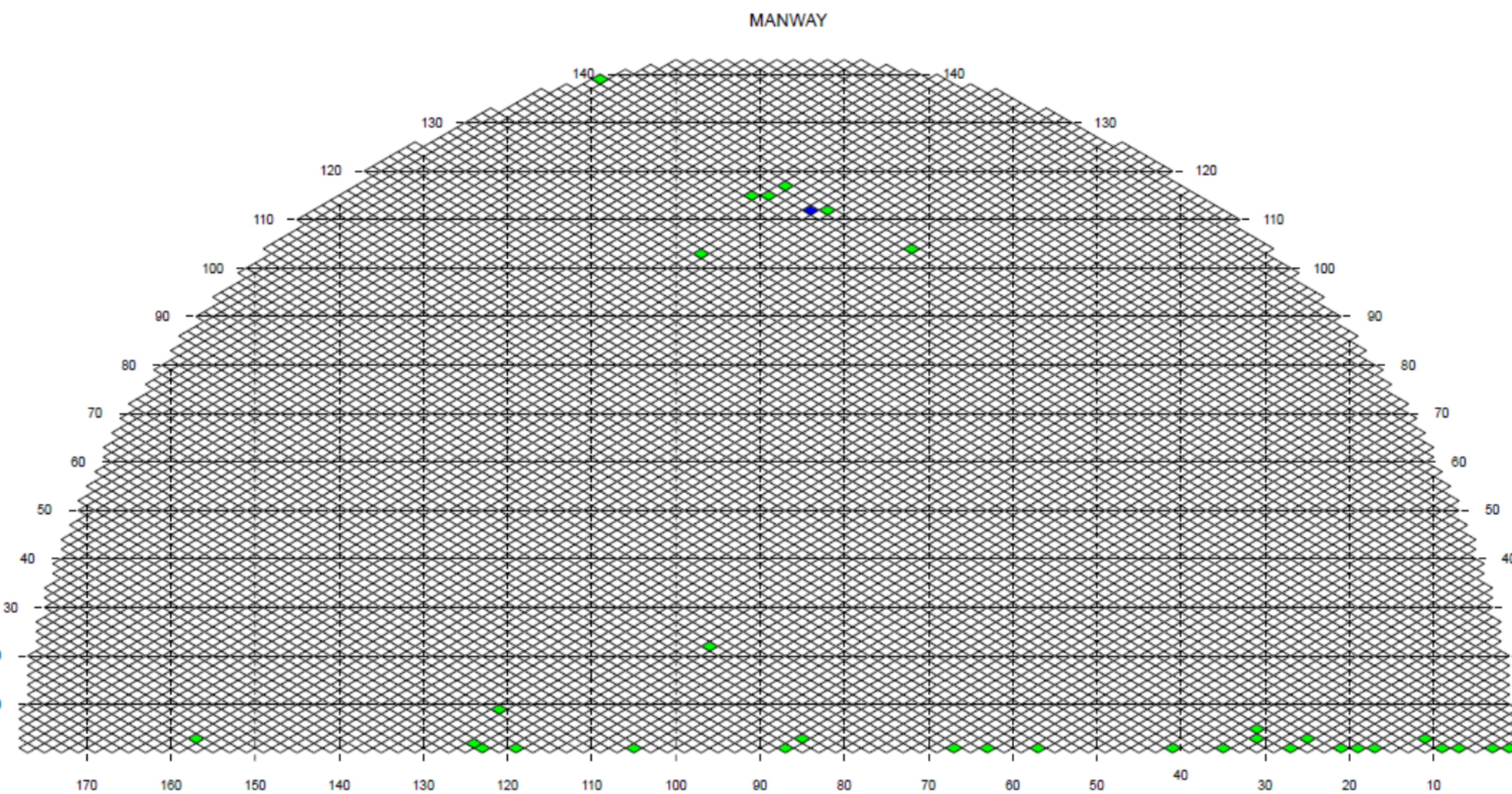
GROUP	TUBES
>=35% tWD	0
20-34% TWD	1
<20% tWD	33

AREVA - FDMS map module Version 11.0

SCALE: 0.066571 X
Sun Feb 19 22:29:09 2012

S/G 89 Repl
COLD
PRIMARY FACE

TOTAL TUBES: 9727
SELECTED TUBES: 34
OUT OF SERVICE (#): NA



SCE-SONGS Unit 2 - REPL
Retainer Bar Wear Indications

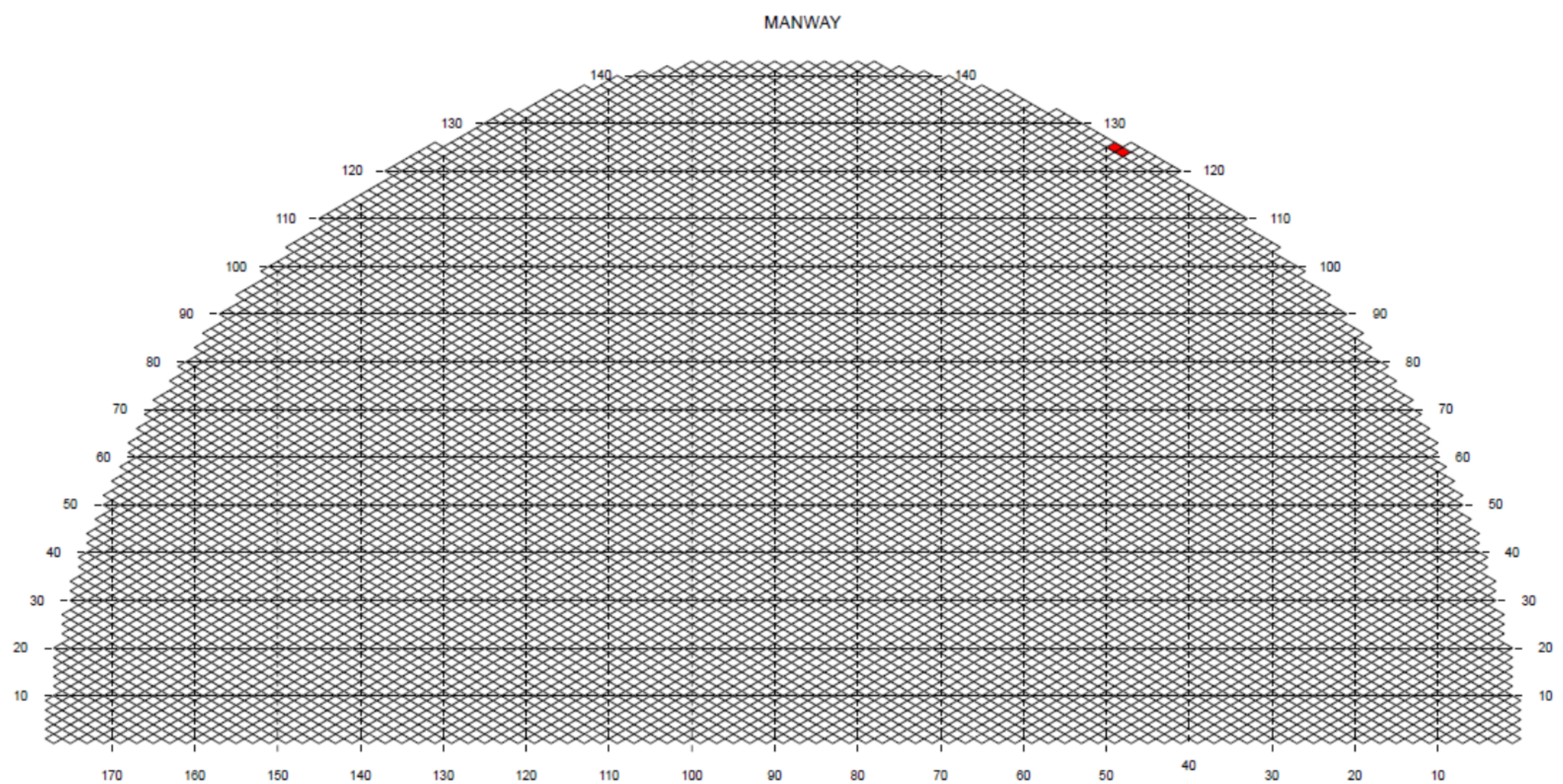
GROUP	TUBES
B03	2

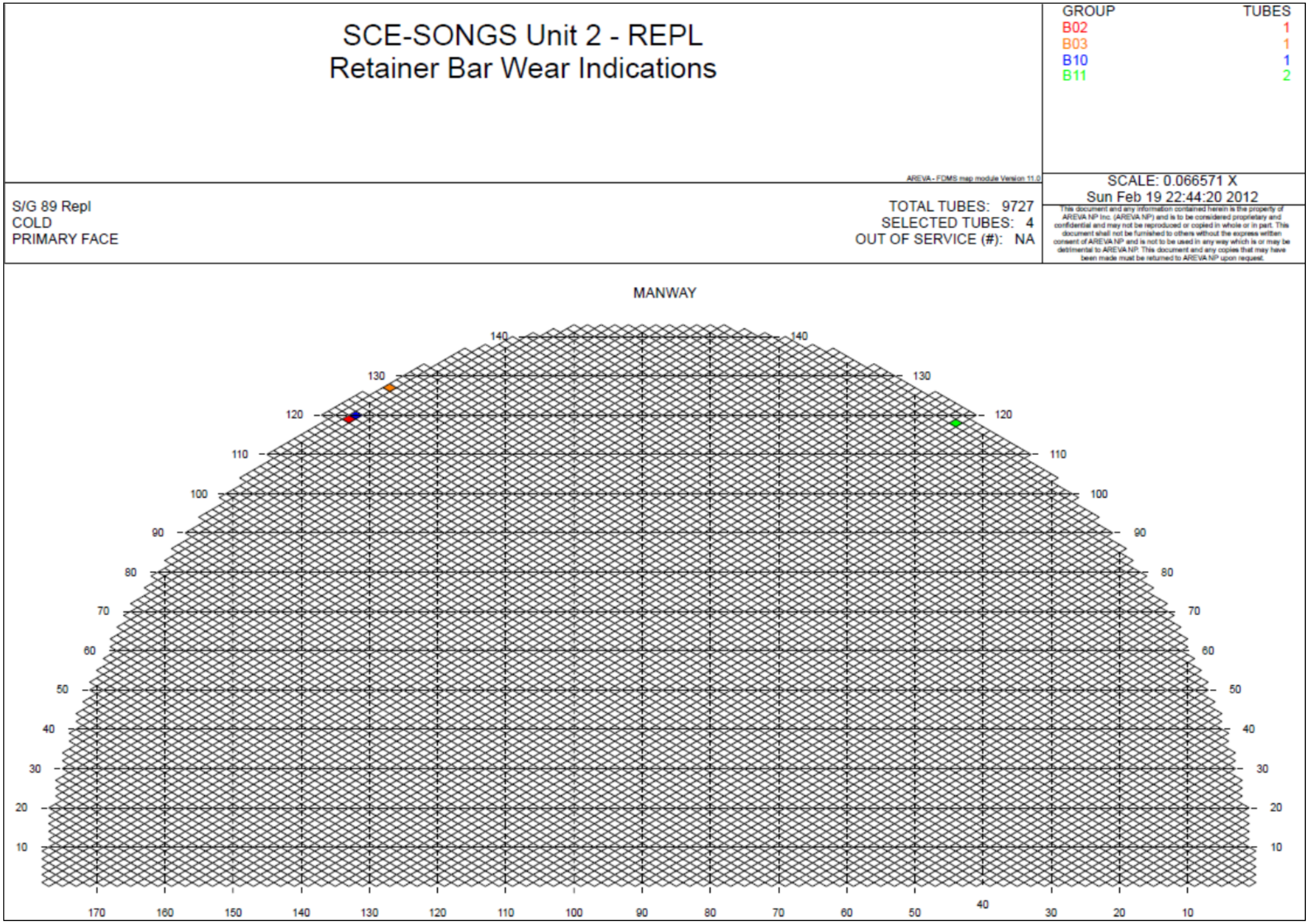
AREVA - FDMS map module Version 11.0

SCALE: 0.066571 X
Sun Feb 19 22:39:14 2012

S/G 88 Repl
COLD
PRIMARY FACE

TOTAL TUBES: 9727
SELECTED TUBES: 2
OUT OF SERVICE (#): NA




SCE-SONGS Unit 2 - REPL
Retainer Bar Wear Indications
GROUP TUBES
B02 1
B03 1
B10 1
B11 2
AREVA - FDMS map module Version 11.0
SCALE: 0.066571 X
Sun Feb 19 22:44:20 2012
S/G 89 Repl
COLD
PRIMARY FACE
TOTAL TUBES: 9727
SELECTED TUBES: 4
OUT OF SERVICE (#): NA
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MANWAY
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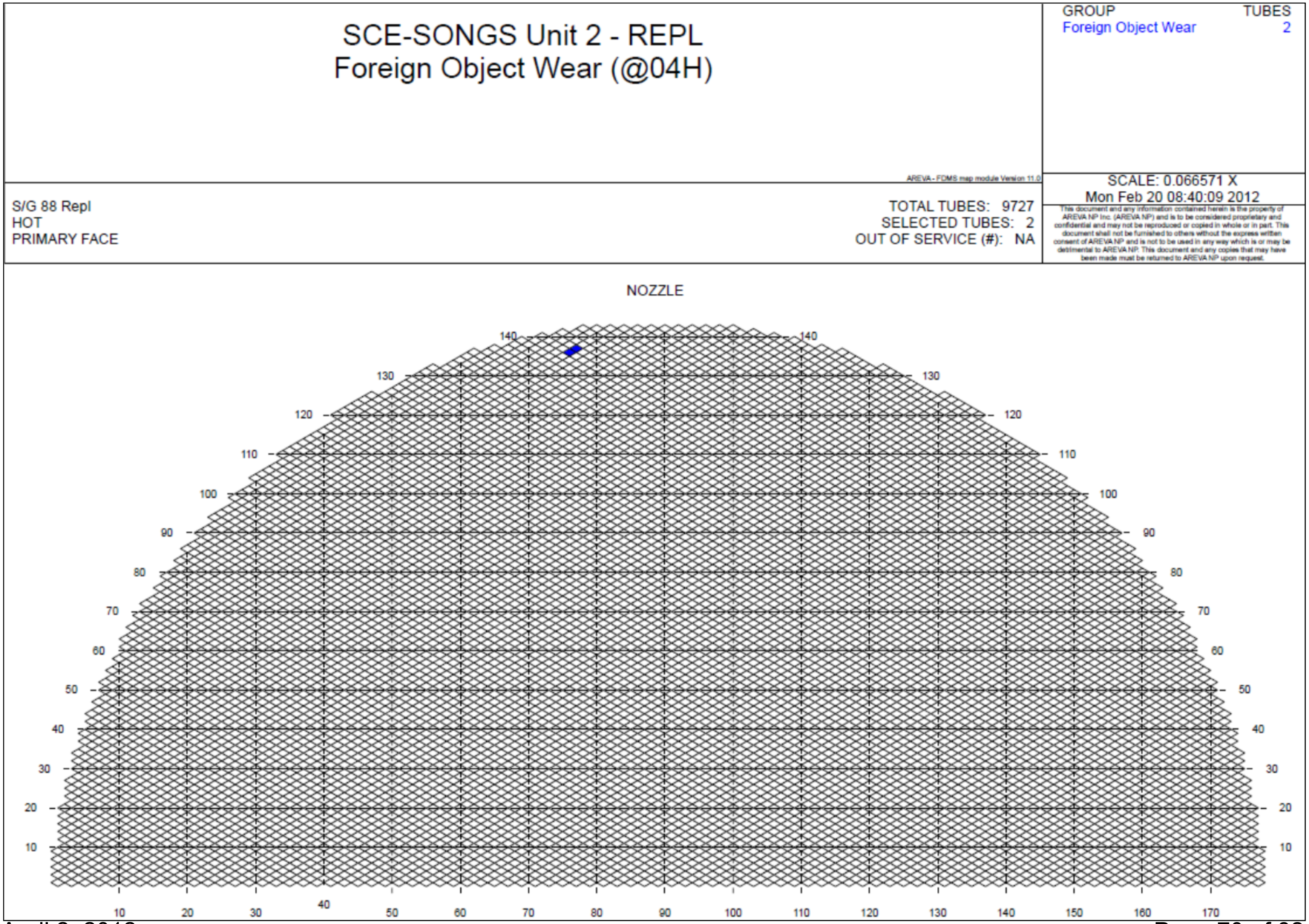
SCE-SONGS Unit 2 - REPL
Foreign Object Wear (@04H)
GROUP
TUBES
Foreign Object Wear
2
AREVA - FDMS map module Version 11.0
SCALE: 0.066571 X
Mon Feb 20 08:40:09 2012
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S/G 88 Repl
HOT
PRIMARY FACE
TOTAL TUBES: 9727
SELECTED TUBES: 2
OUT OF SERVICE (#): NA
NOZZLE
140
130
120
110
100
90
80
70
60
50
40
30
20
10
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170

Attachment 7 - Unit 3 Eddy Current Testing (ECT) Summary

Steam Generator - 3E088

Through Wall Thickness Percentage, Number of Tubes

	>= 50%	35-49%	20-34%	10-19%	<10%	Total
U-Bend Free span Wear	26	18	18	7	0	69
TSP Wear	48	25	14	55	11	153
AVB Wear	0	2	48	298	346	694
Retainer Bar Wear	0	2	1	0	0	3
Foreign Object Wear	0	0	0	0	0	0
Totals	**74**	**47**	**81**	**360**	**357**	**919**

Note: Each tube with wear is only shown once in the above table for number of tubes. The depth category represents the maximum depth in a given tube. The location category is the location of the deepest flaw.

Tubes with no indications = 8808

Steam Generator - 3E089

Through Wall Thickness Percentage, Number of Tubes

	>= 50%	35-49%	20-34%	10-19%	<10%	Total
U-Bend Free span Wear	16	29	13	9	0	67
TSP Wear	44	39	20	27	9	139
AVB Wear	0	0	14	243	423	680
Retainer Bar Wear	0	1	0	0	0	1
Foreign Object Wear	0	0	0	0	0	0
Totals	**60**	**69**	**47**	**279**	**432**	**887**

Note: Each tube with wear is only shown once in the above table for number of tubes. The depth category represents the maximum depth in a given tube. The location category is the location of the deepest flaw.

Tubes with no indications = 8840

Steam Generator - 3E088

Through Wall Thickness Percentage, Number of Indications

	>= 50%	35-49%	20-34%	<20%	Total
U-Bend Free span Wear	50	117	136	110	413
TSP Wear	117	217	506	596	1436
AVB Wear	0	3	156	3199	3358
Retainer Bar Wear	0	2	1	0	3
Foreign Object Wear	0	0	0	0	0
Totals	**167**	**339**	**799**	**3905**	**5210**

Steam Generator - 3E089

Through Wall Thickness Percentage, Number of Indications

	>= 50%	35-49%	20-34%	<20%	Total
U-Bend Free span Wear	26	102	215	73	416
TSP Wear	91	252	487	684	1514
AVB Wear	0	0	45	3104	3149
Retainer Bar Wear	0	1	0	0	1
Foreign Object Wear	0	0	0	0	0
Totals	**117**	**355**	**747**	**3861**	**5080**

Attachment 8 - Safety Culture Assessment

This assessment was performed recognizing the MHI will be performing an RCE for the same issue. Each of the safety culture aspects was considered based on all available information. The assessment determined that there was one potential SONGS related safety culture aspect that may be a contributing cause to this event. The evaluation team did identify two potential aspects that apply to the MHI evaluation but the actual determination cannot be made until the MHI report is delivered.

Human Performance - Decision -Making: Licensee decisions demonstrate that nuclear safety is an overriding priority.

H.1 (a): The licensee makes safety-significant or risk-significant decisions using a systematic process, especially when faced with uncertain or unexpected plant conditions, to ensure safety is maintained. This includes formally defining the authority and roles for decisions affecting nuclear safety, communicating these roles to applicable personnel, and implementing these roles and authorities as designated and obtaining interdisciplinary input and reviews on safety significant or risk-significant decisions.

Answer: Not Applicable

H.1 (b): The licensee uses conservative assumptions in decision making and adopts a requirement to demonstrate that the proposed action is safe in order to proceed rather than a requirement to demonstrate that it is unsafe in order to disapprove the action, the licensee conducts effectiveness reviews of safety-significant decisions to verify the validity of the underlying assumptions, identify possible unintended consequences, and determine how to improve future decisions.

Answer: Not Applicable

H.1 (c): The licensee communicates decisions and the basis for decisions to personnel who have a need to know the information in order to perform work safely, in a timely manner.

Answer: Not Applicable

Human Performance - Resources: The licensee ensures that personnel, equipment, procedures, and other resources are available and adequate to assure nuclear safety. Specifically, those necessary for:
H.2 (a): Maintaining long term plant safety by maintenance of design margins, minimization of long-standing equipment issues, minimizing preventative maintenance deferrals, and ensuring maintenance and engineering backlogs which are low enough to support safety.

Answer: Not Applicable

H.2 (b): Training of personnel and sufficient qualified personnel to maintain work hours within working hour guidelines.

Answer: Not Applicable

H.2(c): Complete, accurate and up-to-date design documentation, procedures, and work packages, and correct labeling of components.

Answer / Basis: Potentially Applicable – As a part of the design scale up process, the length of the retainer bar was increased and the diameter was decreased. It is not clear that MHI performed a change analysis on the design change which should have been controlled by the design control procedures.

H.2 (d): Adequate and available facilities and equipment, including physical improvements, simulator fidelity and emergency facilities and equipment.

Answer: Not Applicable

Human Performance - Work Control: The licensee plans and coordinates work activities, consistent with nuclear safety. Specifically (as applicable):

H.3(a): The licensee appropriately, plans work activities by incorporating: a) risk insights; b) job site conditions (including environmental conditions which may impact human performance); c) plant structures, systems, and components;
Human-system interface; d) or radiological safety; and e) the need for planned contingencies, compensatory actions, and abort criteria?

Answer: Not-Applicable

H.3(b): The licensee appropriately coordinates work activities by incorporating actions to address: a) the impact of changes to the work scope or activity on the plant and human performance; b) the impact of the work on different job activities, and the need for work groups to maintain interfaces with offsite organizations, and communicate, coordinate, and cooperate with each other during activities in which interdepartmental coordination is necessary to assure plant and human performance; c) the need to keep personnel apprised of work status, the operational impact of work activities, and plant conditions that may affect work activities; and d) the licensee plans of work activities to support long-term equipment reliability by limiting temporary modifications, operator workarounds, safety systems unavailability, and reliance on manual actions. Maintenance scheduling is more preventive than reactive.

Answer: Not Applicable

Human Performance - Work Practices: Personnel work practices support human performance. Specifically:

H.4 (a): The licensee communicates human error prevention techniques, such as holding pre-job briefings, self and peer checking, and proper documentation of activities. These techniques used are commensurate with the risk of the assigned task, such that work activities are performed safely. Personnel are fit for duty. In addition, personnel do not proceed in the face of uncertainty or unexpected circumstances.

Answer: Not Applicable.

H.4 (b): The licensee defines and effectively communicates expectations regarding procedural compliance, and personnel follow procedures.

Answer: Not Applicable

H.4(c): The licensee ensures supervisory and management oversight of work activities, including contractors, such that nuclear safety is supported.

Answer: Pending – Although Edison provided the required oversight and augmented the oversight process, determination that this aspect does or does not apply will occur after the MHI causal analysis is complete.

Problem Identification and Resolution - Corrective Action Program: The licensee ensures that issues potentially impacting nuclear safety are promptly identified, fully evaluated, and that actions are taken to address safety issues in a timely manner, commensurate with their significance.

P.1 (a): The licensee implements a corrective action program with a low threshold for identifying issues. The licensee identifies such issues completely, accurately, and in a timely manner commensurate with their safety significance.

Answer: Not-Applicable

P.1 (b): The licensee periodically trends and assesses information from the CAP and other assessments in the aggregate to identify programmatic and common cause problems. The licensee communicates the results of the trending to applicable personnel.

Answer: Not-Applicable

P.1(c): The licensee thoroughly evaluates problems such that the resolutions address causes and extent of conditions, as necessary. This includes properly classifying, prioritizing, and evaluating for operability and reportability conditions adverse to quality. This also includes, for significant problems, conducting effectiveness reviews of corrective actions to ensure that the problems are resolved.

Answer: Not-Applicable

P.1 (d): The licensee takes appropriate corrective actions to address safety issues and adverse trends in a timely manner, commensurate with their safety significance and complexity.

Answer: Not-Applicable

P.1 (e): If an alternative process (i.e., a process for raising concerns is an alternate to the licensee's corrective action program or line management) for raising safety concerns exists, then it results in appropriate and timely resolutions of identified problems.

Answer: Not Applicable

Problem Identification and Resolution - Operating Experience: The licensee uses operating experience (OE) information, including vendor recommendations and internally generated lessons learned, to support plant safety. Specifically (as applicable):

P.2 (a): The licensee systematically collects, evaluates, and communicates to affected internal stakeholders in a timely manner relevant internal and external OE.

Answer: Not Applicable

P.2 (b): The licensee implements and institutionalizes OE through changes to station processes, procedures, equipment, and training programs.

Answer: Not-Applicable

Problem Identification and Resolution - **Self and Independent Assessments**: The licensee conducts self-and independent assessments of their activities and practices, as appropriate, to assess performance and identify areas for improvement. Specifically (as applicable):

P.3 (a): The licensee conducts self-assessments at an appropriate frequency; such assessments are of sufficient depth, comprehensive, appropriately objective, and are self-critical. The licensee periodically assesses the effectiveness of oversight groups and programs such as CAP, and policies.

Answer: Not-Applicable

P.3 (b): The licensee tracks and trends safety indicators which provide an accurate representation of performance.

Answer: Not Applicable

P.3(c): The licensee coordinates and communicates results from assessments to affected personnel and takes corrective action to address issues commensurate with their significance.

Answer: Not-Applicable

Safety Conscious Work Environment- Environment for Raising Concerns:
An environment exists in which employees feel free to raise concerns both to their management and/or the NRC without fear of retaliation and employees are encouraged to raise such concerns. Specifically (as applicable):

S.1 (a): Behaviors and interactions encourage free flow of information related to raising nuclear safety issues, differing professional opinions, and identifying issues in the CAP and through self-assessments. Such behaviors include supervisors responding to employee safety concerns in an open, honest, and non-defensive manner and providing complete, accurate, and forthright information to oversight, audit, and regulatory organizations. Past behaviors, actions, or interactions that may reasonably discourage the raising of such issues are actively mitigated. As a result, personnel freely and openly communicate in a clear manner conditions or behaviors, such as fitness for duty issues that may impact safety and personnel raise nuclear safety issues without fear of retaliation.

Answer: Not Applicable

S.1(b): If alternative processes.(i.e., a process for raising concerns or resolving differing professional opinions that are alternates to the licensees corrective action program or line management) for raising safety concerns or resolving differing professional opinions exists, then they are they communicated, accessible, have an option to raise issues in confidence, and are independent, in the sense that the program does not report to line management (i.e., those who would in the normal course of activities be responsible for addressing the issue raised).

Answer: Not Applicable

Safety Conscious Work Environment - Preventing, Detecting, and Mitigating Perceptions of Retaliation: A policy for prohibiting harassment and retaliation for raising nuclear safety concerns exists and is consistently enforced in that:

S.2 (a): All personnel are effectively trained that harassment and retaliation for raising safety concerns is a violation of law and policy and will not be tolerated.

Answer: Not Applicable

S.2 (b): Claims of discrimination are investigated consistent with the content of the regulations regarding employee protection and any necessary corrective actions are taken in a timely manner, including actions to mitigate any potential chilling effect on others due to the personnel action under investigation.

Answer: Not Applicable

S.2(c): The potential chilling effects of disciplinary actions and other potentially adverse personnel actions (e.g., reductions, outsourcing, and reorganizations) are considered and are compensatory actions are taken when appropriate.

Answer: Not Applicable

Other Safety Culture Components - Accountability: Management defines the line of authority and responsibility for nuclear safety. Specifically (as applicable):

O.1 (a): Accountability is maintained for important safety decisions in that the system of rewards and sanctions is aligned with nuclear safety policies and reinforces behaviors and outcomes which reflect safety as an overriding priority.

Answer: Not Applicable

O.1 (b): Management reinforces safety standards and displays behaviors that reflect safety as an overriding priority.

Answer: Not-Applicable

O.1(c): The workforce demonstrates a proper safety focus and reinforces safety principles among their peers.

Answer: Not-Applicable

Other Safety Culture Components - Continuous Learning Environment: The licensee ensures that a learning environment exists. Specifically (as applicable):

O.2 (a): The licensee provides adequate training and knowledge transfer to all personnel on site to ensure technical competency.

Answer: Not Applicable

O.2 (b): Personnel continuously strive to improve their knowledge, skills, and safety performance through activities such as benchmarking, being receptive to feedback, and setting performance goals. The licensee effectively communicates information learned from internal and external sources about industry and plant issues.

Answer: Not Applicable

Other Safety Culture Components - Organizational Change Management:
O.3: Management uses a systematic process for planning, coordinating, and evaluating the safety impacts of decisions related to major changes in organizational structures and functions, leadership, policies, programs, procedures, and resources. Management effectively communicates such changes to affected personnel.

Answer: Not-Applicable

Other Safety Culture Components - Safety Policies: Safety policies and related training establish and reinforce that nuclear safety is an overriding priority in that:

O.4 (a): These policies require and reinforce that individuals have the right and responsibility to raise nuclear safety issues through available means, including avenues outside their organizational chain of command and to external agencies, and obtain feedback on the resolution of such issues.

Answer / Basis: Not Applicable

O.4 (b): Personnel are effectively trained on these policies.

Answer: Not Applicable

O.4(c): Organizational decisions and actions at all levels of the organization are consistent with the policies. Production, cost and schedule goals are developed, communicated, and implemented in a manner that reinforces the importance of nuclear safety.

Answer / Basis: Not-Applicable

O.4 (d): Senior managers and corporate personnel periodically communicate and reinforce nuclear safety such that personnel understand that safety is of the highest priority.

Answer: Not Applicable

Attachment 9 - Reference Documents

NRC Commitments

1. Title 10 Code of Federal Regulations, Part 50, Section 55a (b) (2) (iii).
2. ASME Boiler and Pressure Vessel Code, Section XI, Rules for InserviceInspection of Nuclear Power Plant Components, 1995 Edition, including1996 Addenda.
3. Unit 2 and Unit 3 Technical Specifications, Section 5.5.2.11, SteamGenerator (SG) Program.
4. San Onofre Nuclear Generating Station, Topical Quality Assurance Manual(TQAM), Chapter 7-E, ASME Code Program - Inservice Inspection.
5. Letter from W.C. Marsh (Southern California Edison) to Document ControlDesk (U.S. Nuclear Regulatory Commission) dated June 27, 1995; Subject:Response to Generic Letter 95-03, Circumferential Cracking of SteamGenerator Tubes.

Orders/Procedures

1. SO23-SG-1, Steam Generator Program
2. SO23-XXXIII-4.2, Steam Generator Tube Inspection and Corrective Action.

Others

1. NEI 97-06, Revision 3, January 2011, Steam Generator Program Guidelines
2. NEI 97-06, “SG Program Guidelines,” Rev. 2, September 2005.
3. EPRI Report 1019038, “SG Integrity Assessment Guidelines: Revision 3”, November 2009.
4. EPRI Report 1013706, “PWR SG Examination Guidelines: Revision 7”, October 2007.
5. EPRI Report 1014983, “Steam Generator In-Situ Pressure Test Guidelines, Revision 3”, August 2007.
6. EPRI Report 1019037 “Steam Generator Degradation Specific Management Flaw Handbook, Revision 1”, December 2009.
7. AREVA Report 51-9177491-000; “SONGS 2C17 Steam Generator Condition Monitoring and Preliminary Operational Assessment,” February 2012

MHI Documents

1. MHI Report L5-04GA561, Rev. 1 (SONGS SO23-617-1-M1562, Rev. 1) "Retainer Bar Tube Wear Report," March 2012.
2. MHI Report L5-04GA419, Rev. 4 (SONGS SO23-617-1-C749, Rev. 4) "Analytical Report of AVB Assembly," June 2008.
3. MHI Report L5-04GA433, Rev. 4 (SONGS SO23-617-1-C1262, Rev. 4) "Regulatory Guide 1.121 Analysis" July 2008.
4. MHI Drawing L5-04FU111, Rev. 2 (SONGS SO23-617-1-D507, Rev. 5) "Anti-Vibration Bar Assembly 1/9," October 2006
5. MHI Drawing L5-04FU117, Rev. 9 (SONGS SO23-617-1-D542, Rev. 9) "Anti-Vibration Bar Assembly 7/9," March 2007
6. MHI Report L5-04GA101, Rev. 0 (SONGS SO23-617-1-M1385, Rev. 0) "Nitrogen Plenum / Accelerometer Data Reports, Unit 2" March 2009.
7. MHI Report L5-04GA102, Rev. 0 (SONGS SO23-617-1-M1508, Rev. 0) "Nitrogen Plenum / Accelerometer Data Reports, Unit 2" December 2010

Meeting Minutes

1. Meeting Minutes, AVB Team Meeting, August 15, 2005
2. Meeting Minutes, SONGS RSG Executive Oversight Meeting, August 16, 2005
3. Design Review/Technical Meeting Agenda Revision 1, August 17 – 19, 2005
4. MHI Presentation on Technical Discussion on RSG Performance Topics, August 2005
5. Technical Discussion Meeting of AVB Design Team (Handout), September 16, 2005
6. Design & Technical Review Meeting Minutes (DRM #6), October 17-21, 2005
7. Meeting Minutes of #8 Design Review and Technical Meeting, March 13 – 17, 2006
8. MHI Presentation on Technical Discussion of Anti-Vibration Bar Fabrication, March 13, 2006
9. Meeting Minutes, Technical Exchange Meeting , June 2, 2006
10. Meeting Minutes, #10 Design Review and Technical Meeting, September 12-15, 2006
11. Meeting Minutes, #11 Design Review and Technical Meeting, March 27- 30, 2007
12. MHI Presentation on Technical Discussion for Anti-Vibration Bar Assembly Fabrication, March 29, 2007

Non-Conformance Reports

1. Non-Conformance Report UGNR-SON2-RSG-067, Rev. 7 “Unacceptable Gaps between Tubes and AVBs, January 2007
2. Non-Conformance Report UGNR-SON2-RSG-075, Rev. 1 “Unacceptable Gaps between Tubes and AVBs, March 2007
3. Non-Conformance Report UGNR-SON3-RSG-024, Rev. 1 “Gaps between Tubes and AVBs are larger than the Criterion, December 2007
4. Non-Conformance Report UGNR-SON3-RSG-030, Rev. 0 “Gaps between Tubes and AVBs are larger than the Criterion, March 2008

Notifications/SAP Orders

1. 201836127, Steam Generator Tube Leak, Unit 3, 1/31/2012
2. 201843216, Steam Generator Tube Wear at Retainer Bars, 2/5/2012
3. 201775726, Spurious VLPM (3L194) Alarms, 12/18/2011
4. 201820313, Spurious Unit 3 VLPMS Alarms, 1/20/2012
5. 201146204, Unit 3 RSG Accelerometer Data Review
6. 800071702, NECP, Replacement Steam Generators, Unit 2
7. 800071703, NECP, Replacement Steam Generators, Unit 3
8. 800457837, NECP, Replace Unit 2 VLPMS Monitoring System
9. 800457903, NECP, Replace Unit 3 VLPMS Monitoring System

Cause CA matrix

Cause Evaluation Element	Description	Assignment Number & Type/Assignee/Due Date/Signature:
Problem: *On February 5, 2012, wear indications greater than 35 percent were detected in two locations in Unit 2 steam generator adjacent to retainer bars during the Unit 2 Cycle 17 refueling outage current examinations.*	CAPR1: Removed the 94 steam generator tubes from service at the retainer bar locations in 2E088 and 2E089 in accordance with SO23-SG-1 Steam Generator Program requirements and the Condition Monitoring and Operational Assessment Report (CMOA). *This will prevent vibration between the retainer bar and tubes from creating a leak.*	Assignee: A. Matheny *A. Matheny* Due Date: **Complete** *(This action is complete. This action is being entered into ActionWay to ensure adequate documentation (objective evidence) of performance is provided. The due date is for documentation entry only. Due 5/15/12)*
Interim Actions:	CA1: Obtain the services of industry designers, manufacturers, and consultants to conduct and independently review failure analyses and repair plans pending determination of underlying design and manufacturing issues.	Assignee: B. Sarno *B. S.* Due Date: **Complete** *(This action is complete. This action is being entered into ActionWay to ensure adequate documentation (objective evidence) of performance is provided. The due date is for documentation entry only. Due 5/15/12)*
	CA2: SCE performed 100% tube ECT in accordance with the SG Program and repairs (plugging) on Unit 2. Tubes in the vicinity of the retainer bars were plugged (94 on each SG).	Assignee: A. Matheny *A. Matheny* Due Date: **Complete** *(This action is complete. This action is being entered into ActionWay to ensure adequate documentation (objective evidence) of performance is provided. The due date is for documentation entry only. Due 5/15/12)*
	CA3: Conduct Foreign Object Search and Retrieval (FOSAR) and retrieve any loose parts in Unit 2.	Assignee: A. Matheny *A. Matheny* Due Date: **Complete** *(This action is complete. This action is being entered into ActionWay to ensure adequate documentation (objective evidence) of performance is provided. The due date is for documentation entry only. Due 5/15/12)*
	CA4: MHI to perform vibration analysis on retainer bar and submit to Edison for approval.	Assignee: B. Olech [signature] Due Date: ~~6/15/12~~

	CA5: Conduct a primary system change analysis to verify changes in operating parameters will not have an adverse effect on Unit 2 SG operation.	Assignee: F. Simma F. Simma per telecom 4/2/12 1310 [illegible] Due Date: **Complete** *(This action is complete. This action is being entered into ActionWay to ensure adequate documentation (objective evidence) of performance is provided. The due date is for documentation entry only. Due 5/15/12)*
	CA6: Establish operational limits that will allow operation between start-up and initial mid-cycle inspection.	Assignee: D. Yarbrough D. Yarbrough Due Date: 6/01/2012 per telecon [illegible] 4/2/12 11:10 AM
	CA7: Increase the tube inspection scope and frequency in accordance with the SG Program.	Assignee: A. Matheny A. Matheny Due Date: 6/01/2012
	CA8; Monitor the Unit 3 tube-to-tube wear cause analysis. If it impacts Unit 2 operational limits and mid-cycle inspection dates, generate a notification to track analysis and resolution.	Assignee: A. Matheny A. Matheny Due Date: 6/30/2012
Extent of Condition: This evaluation determines the cause of wear at the retainer bars and other wear locations.	CA9: Remove the 94 steam generator tubes from service at the retainer bar locations in 3E088 and 3E089 in accordance with SO23-SG-1 Steam Generator Program requirements and the Condition Monitoring and Operational Assessment Report.	*The action as written here is intended to address extent of condition. It is the same action as CAPR2 which addresses the mechanistic root cause. See closure documentation for CAPR2.*
	CA10: Perform secondary side visual inspections of both Unit 2 steam generators.	Assignee: A. Matheny A. Matheny Due Date: **Complete** *(This action is complete. This action is being entered into ActionWay to ensure adequate documentation (objective evidence) of performance is provided. The due date is for documentation entry only. Due 5/15/12)*
Mechanistic Root Cause: The retainer bar size was insufficient to prevent excessive flow induced vibration of the bar. Tube wear occurred from vibrational contact between the retainer bars and tubes	CAPR1: Removed the 94 Unit 2 steam generator tubes from service at the retainer bar locations in 2E088 and 2E089 in accordance with SO23-SG-1 Steam Generator Program requirements and the Condition Monitoring and	Assignee: Al Matheny Due Date: **Complete** See 1st action

inside the SGs.	Operational Assessment Report (CMOA). *This will prevent vibration between the retainer bar and tubes from creating a leak.*	
	CA11: Determine additional preventive actions based on findings from Unit 3 cause analysis.	Assignee: Al Matheny A. Matheny Due Date: 6/1/2012
	CA12: Review St. Lucie Unit 2 SG Inspection Results for Third Cycle following replacement for continued applicability of AVB wear rates at SONGS.	Assignee: Al Matheny A. Matheny Due Date: 10/1/2012

Causes: Extent of Cause	CAPR2: Remove the 94 Unit 3 steam generator tubes from service at the retainer bar locations in 3E088 and 3E089 in accordance with SO23-SG-1 Steam Generator Program requirements and the Condition Monitoring and Operational Assessment Report. *This will prevent vibration between the retainer bar and tubes from creating a leak.*	Assignee: Al Matheny A. Matheny Due Date: 6/30/12
Other Actions:	OA1: Chemistry Effluent Engineering perform an evaluation of the Primary to Secondary Leak (PSL) program controls to determine if detection limits can be lowered and if administrative actions can be added to detect low level trends of PSL. Consider the addition of new/improvements to rad-monitoring and changes to plant operations during the event.	Assignee: J. Demlow Due Date: April 30, 2012
	OA2: Evaluate viability of planned T_{Cold} change due to new high pressure turbine installation and its impact on the steam generators.	Assignee: F. Simma Due Date: 4/30/12 repeat of CA-5 delete

	OA3: Management sponsor for RCE to submit to CARB an approved Change Management Plan in accordance with SO123-XV-50.7 within 15 calendar days after CARB approval of the RCE.	Assignee: Determined by CARB Due Date: within 15 calendar days after CARB approval of the RCE.
	OA4: Approve the Condition Monitoring & Operational Assessment Report by AREVA to determine the cycle length for next inspection for operation.	Assignee: Al Matheny A. Matheny Due Date: 6/15/2012
	OA5 review MHI cause analysis report and revise this report based on MHI causes and conclusions.	Assignee: J. Osborne Due Date: 6/30/2012 [signature]
	A FIV analysis was not performed for the small retainer bars. The purpose of this action is to ensure that changes made to a SONGS system that involve components in the flow stream receive some level of vibration analysis. OA6 revise SO123-XXIV-1.1 to require check of vibration analysis for changes to systems involving the flow aspect of the system. (see OE section on previous SONGS events to understand concept)	Assignee: D.Schafer D. Schafer per telecon 4/2/12 11:00 [initials] Due Date: 6/30/2012 [signature]
	OA7: Perform a material analysis on loose part/foreign material at discovered during FOSAR.	Assignee: M. Mostafa M. MOSTAFA per telecom 4/2/12 12:00pm [initials] Due Date: **Complete** *(This action is complete. This action is being entered into ActionWay to ensure adequate documentation of performance is provided and the due date is for documentation entry only. Due 5/15/12)*
	OA8: Conduct a design change review between a proven similar MHI replacement reactor vessel head and the SONGS replacement reactor vessel head to identify design changes and verify those changes received the appropriate level of analysis.	Assignee: B. Patel Due Date: 5/30/12 B.PATEL - PER TELECON 04/02/12 @ 12:45. RL